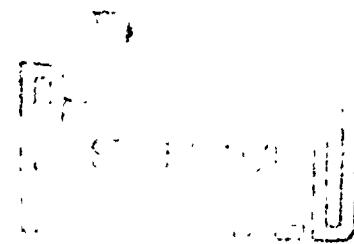AD 674121

FIRE-SERVICE CAPABILITIES
FOR DAMAGE CONTROL AND RESCUE

OCD Work Unit 2512A

Final Report

March 1968

URS

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CORPORATION

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by

S. B. Martin
M. Staackmann
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ACKNOWLEDGEMENTS

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Prepared for

OFFICE OF CIVIL DEFENSE,
Department of the Army
Washington, D. C.   20310

Contract N00228-67-C-0694

Work Unit 2512A

through the

Technical Management Office
U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco, California   94135

Summary Report

of

FIRE-SERVICE CAPABILITIES
FOR DAMAGE CONTROL AND RESCUE

The prospect of nuclear attack on urban areas presents the fire services with extremely serious problems — most of which are not encountered in conventional peacetime operations. Examples include:

1. Demands can far exceed capabilities (particularly if the demands are defined by peacetime standards)

2. Fire-service manpower, resources, and equipment would be degraded by blast effects in many cases

3. Constraints on operational feasibility would be imposed by radiological hazards and by debris, refugee traffic, and massfire effects along routes of travel

4. Psychological factors could hamper fire-service performance

Because of the unpredictability of the distribution of direct nuclear-weapon damage and the resultant residual hazards throughout urban areas, fire-service responses must be preplanned for a range of operational situations. Plans for emergency operations must be prepared for all major contingencies, ranging from no direct weapon effects (and no local demands) to the limit of operational feasibility; and provision must be made for prompt, accurate assessment of threats, demands, and degradation of capability so that effective and realistically chosen responses will result without costly delay when attack occurs. Moreover, threat-assessment guidelines must be consistent with both operational needs and limitations in input information so that, if need be, an on-the-spot unit commander can make a realistic choice of feasible and effective tactics without the aid of higher echelon control. As a minimum, the nine basic operating situations of the OCD Concept of Emergency Operations[*] can be used as a basis for both contingency planning and threat recognition.

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[*] Working draft of material to be incorporated in the Federal Civil Defense Guide (Ref. 1).

The primary objective of the fire-service operations in a nuclear emergency is the protection of the surviving population and critical life-support resources from the threat of fire. The principal determinant of operational feasibility and effectiveness is the controllability of threatening fires (those fires that jeopardize population survival). Tactical plans must be formulated on the realization that not all fires <u>can</u>, or even <u>need to be</u>, controlled, that fire-fighting, per se, will frequently be no more than an adjunct to the primary lifesaving activities of rescue and relocation, and that many time-honored concepts and methods are inappropriate to nuclear emergencies.

Interim guidelines are available for aiding the development of fire-service plans and procedures for nuclear emergencies. At the present time, fire research is attempting to define the categories of fire threat in such a way that (1) guidance in the recognition and forecasting of fire threats is provided, (2) realistic modes of operation for the various fire-threat contingencies can be prescribed, and (3) effective tactics can be chosen. Significant progress has already been made toward these objectives. Some information is now available for developing preliminary, but useful guidelines for designating fire controllability and relating operational feasibility and effectiveness to it.

Another important element in determining fire-service capabilities is the establishment of resource and manpower requirements for various firefighting and lifesaving functions. Information derived from peacetime operations is available, but for various reasons discussed in the report, it is of limited utility in application to problems of nuclear emergency. However, the existing information has been used together with some first-principle considerations to derive a set of relationships for quantitatively evaluating fire-control and rescue activities.

Briefly summarized, the research reported accomplished the following:

1. Development of analytical methods and preliminary performance models.

2. Studies of specific cases to test the analytical methods and to provide a preliminary evaluation of some operational concepts.

The final report also treats the following subjects:

1. Feasibility of various strategies and tactics for the range of
   conditions following nuclear attack.

2. Guidelines for determining optimal tactical decisions when
   information is limited.

3. Resource and manpower requirements for typical firefighting and
   rescue operations.

4. Rationale for allocating services to demands.

5. Basic concepts of a formal method for evaluating fire-service
   performance in postattack environments.

Most of these are interim or incomplete results. A follow-on study is recommended
for bringing this research to a conclusive stage and to apply its results to
some specific civil defense situations.

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Section 1

INTRODUCTION

Fire services, as currently constituted in the United States, are not designed to cope with a nuclear attack situation. This fact has, for some time, been recognized by fire-service authorities and others and is a matter of great concern to them and to those who must plan civil defense actions. It is incumbent upon the latter group to evaluate the capabilities of fire-service organizations as presently constituted, as well as the potential capabilities of realistic future modifications of the fire services of the nation, to perform the tasks of damage control and rescue under conditions of nuclear attack. thereby providing guidance to fire-service planning.

The environmental conditions created by the nuclear attack generate the need for damage-control and rescue activities, but the environment may be so hostile as to prevent accomplishment of the tasks. The magnitude of the demands, hazards, and obstacles seem overwhelming, at first sight. Indeed the point has been made repeatedly, from largely intuitive considerations, that conventional fire services would be totally overwhelmed by the urban fires resulting from nuclear attack. And yet our experiences with fire in World War II indicate that many human lives can be saved even in situations where the fires cannot be controlled. The Hamburg Fire Protection Service is credited with saving many thousands of lives from the historic firestorm in that city — and this was accomplished without the benefit of planning based on prior experience with fires of such magnitude. The lifesaving and property-saving capability of urban fire services, both as they exist and serving as a nucleus of a fire-defense and rescue system, should be evaluated in as quantitative a fashion as the state of the art allows.

BACKGROUND

This final report summarizes the first 2 year's effort of a continuing research program. Initial work under the first year's contract was applied to an examination of specific approaches to handling damage control and rescue problems, to determination of fire-environment descriptions for specific weapon characteristics and building construction types, and to consideration of factors governing the effective performance of various fire control and rescue activities.

Approximately 9 months after the start of the initial contract period, a conference with OCD and NRDL coordinators of the contract was held to review the program. This review resulted in a reorientation of the general approach. The change was initiated to ensure development of a generalized analytical scheme for evaluating the probable effectiveness of a wide spectrum of conceivable fire-service postures and strategies under the widely variable conditions following nuclear attack situations.

OBJECTIVES

As stated in the second year's contract (No. N00228670694), the intent of the research effort is to "continue and expand the research work previously undertaken towards the objective of developing a general analytical method for the evaluation of fire-service effectiveness in dealing with damage control and rescue requirements following a nuclear attack."

The following long-term objectives are taken from the Scope of Work of the second year's contract:

1. The development of an evaluation model for determining the capabilities of fire services to perform damage control and rescue in the postattack environment in relation to expenditures of effort and resources. The model will be used to compare alternative fire-service organizations and attack configurations and should be suitable for finding the optimal (or preferred) systems for a variety of circumstances.

2. An examination of key components within municipal organization and urban planning that do, or could, significantly affect fire-service capabilities to perform damage control or rescue work after a nuclear attack. These factors represent some of the controllable variables of the evaluation model. Since the primary objective of the research effort is to develop an evaluation model, probably only a superficial examination of this subject will be possible within the limitations of time and funds.

SCOPE OF WORK REPORTED

The foregoing objectives are long-term goals of a research program which was planned to reach an interim stage during the contract period just concluded. Reasonable goals for the contract period were stated in the first quarterly progress report (Ref. 2) and can be summarized as follows:

1. To develop analytical methods and preliminary performance models for the evaluation of fire-service capability in the immediate postattack environment.

2. To study specific, hypothetical cases of nuclear attack on urban targets as a test of the utility of the analytical methods.

These goals have all been accomplished.

In developing the analytical methods, the scope of the study was limited to fire services as they are presently constituted, that is, with current manpower levels, equipped for peacetime demands, and without specially supplied resources other than those which might reasonably be procured during a relatively short period of international crisis. Within these limitations (i.e., essentially fixed-cost restrictions), the variable factors to be studied are operational variables (those relating to deployment, preattack planning, and postattack tactics) and threat variables (those relating to damage and continuing hazards resulting from the attack).

The primary effort was given to developing analytical methods for evaluating the feasibility and effectiveness of candidate tactics for a set of threat contingencies.

1-3

The analytical methods were tested through a series of hand-calculation exercises for a selected area of an example city. The intention was to provide (1) a preliminary evaluation of some logically important variations in operational variables for two significantly different sets of threat variables and (2) a test for unmanageable or deficient elements of the analytical methods.

Section 2
PROBLEM DESCRIPTION AND RESEARCH APPROACH

The capability of a fire-service organization to perform damage control and rescue tasks in the immediate postattack emergency period depends primarily on (1) the nature and location of the demands (which are principally the protection of the surviving population), (2) the amount and location of surviving fire-service resources, and (3) the impediments to fire-service response and activity imposed by the effects of the attack. To accomplish an analysis of this capability for any given situation requires a rather detailed description of the immediate postattack urban environment and an extensive evaluation of the possible lifesaving and property-saving accomplishments of each surviving element of the fire-service organization as it might engage in any of a number of alternative operational activities. The description of the emergency-period environment requires an analysis both of the direct damage and of fire and fallout threats as they develop with time. From this an estimate of damage to water supplies and debris levels along routes of travel can be derived as well as the damage to equipment and incapacitation of personnel for every preattack deployment strategy under consideration. It is necessary to identify possible roles of the surviving elements of the fire service, that is, their operational objectives and all feasible tactics they might employ to achieve their objectives for each applicable case of a wide range of environmental conditions. Finally, the effectiveness of each tactic must be evaluated and compared with its alternatives for the range of conditions and a similarly broad range of demands.

Such a single-case analysis is an impressive undertaking, and its results, while they may be indicative of general capability, can only be relied upon for the specific case studied. For the amount of work involved, it is desirable to obtain results of general applicability. The research reported here is directed toward the

development of generally applicable procedures for evaluating fire-service performance. Considering the many variables and their wide ranges of possible values, some simplifications must be sought.

Research Approach

The approach taken in this study was to attempt to identify the role of the fire services in nuclear-attack-emergency operations for a relatively small number of operationally distinct situations. This was done by first reviewing peacetime practices and wartime experiences of fire services and then relating these to the conditions and demands of nuclear attack on urban centers. Examples of operationally distinct situations were derived from the current OCD Concept of Emergency Operations (Ref. 1). The results of research in nuclear weapon effects, particularly fire initiation and spread, were explored in search of unambiguous definitions of fire controllability and other constraints on operational feasibility, from which a set of operational objectives of the fire services, the corresponding tactical alternatives, and their component activities can be ascertained.

This, the problem-definition part of the research, is presented in Sections 3 and 4 of this report. Section 3 reviews fire-service operation in non-nuclear emergencies. Section 4 discusses the special environmental constraints imposed by nuclear attack that limit operational feasibility and develops concepts of fire-service operation in nuclear emergencies.

Once the problem was defined in manageable terms, attention was directed to the concepts and mechanics of analyzing fire-service performance. Analytical expressions for quantitatively evaluating the effort and resource requirements for accomplishing tactical missions of fire control, rescue, and relocation were derived either from first principles or from empirical data wherever available in suitable form.

Finally, two specific cases of a selected section of an urban area after hypothetical nuclear attack were studied to discover deficiencies in the analytical methods and to test the validity of assumptions regarding fire controllability. The development of the methods for analyzing fire-service performance are discussed in Sections 5 and 6. The results of the research to date and their applicability to both research and operational planning are discussed in Section 7 along with recommendations for follow-on research designed to fully exploit the results reported here.

Section 3
REVIEW OF FIRE-SERVICE OPERATIONS IN NON-NUCLEAR EMERGENCIES

In this section the conventional modes of operation of the fire services in peacetime and the special problems encountered by the fire services in the large-scale urban fires of World War II will be explored in search of guidance to concepts of operation in nuclear emergencies.

PEACETIME OPERATIONS

Metropolitan fire departments in the United States are organized, trained, and equipped to combat fires for the purpose of protecting life and property threatened by fire. The cardinal rule, traditionally, has been to save lives first and property second. The annual statistics (Ref. 3) show that in peacetime fires having large losses in life (excluding cases of deaths resulting from smoking in bed, for example), by far the largest loss of life results from people being trapped in burning buildings. This threat to human life has been countered by the fire services through the development and application of specialized rescue devices and techniques. Because of this, the fire services are called upon to perform rescue functions even when fire is not involved; and an extention of this role into wartime situations is generally assumed. This assumption would be a good one for most cases since the fire services would be performing their primary function of saving lives. Under certain conditions, however, it would be desirable to have other forces available to perform rescue functions in non-fire situations, releasing the fire services for duty in fire areas. Other conditions may indicate that a greater saving of lives could be achieved by utilizing the fire services in fire-involved areas only.

Statistics (Ref. 3) also show that total loss in life during peacetime is small in relation to the number of buildings involved in fire; and, generally speaking, the

principal effort of the metropolitan fire department is given to reducing property losses due to fire. Moreover, it is a rare circumstance when a metropolitan fire department has to deal with a fire that involves more than a few buildings at a time. Because of the typically low level of demand, fire services are usually not designed to handle large-area fires without outside help. This is the basis for the mutual-aid agreements between neighboring communities.

The primary function of a metropolitan fire department in a typical peacetime operation is usually described as "firefighting," which can be divided into the component functions "fire extinguishment" and "control of fire spread." However, these functions are much too broad in scope for their performance to be evaluated. A somewhat more detailed description in terms of separate tasks and how they change with time can be derived from the chronology of a fire of nonexplosive origin that does not involve liquid fuels to any appreciable extent. The steps in the development of such a fire can be related in a simplified and idealized fashion as follows:

1. The heat and/or flame from a small source, e. g. , a match, cigarette, faulty wiring, overheated equipment, etc. , ignites a fine tinder fuel such as paper, cardboard, or cloth.

2. The secondary source ignites a larger object, such as draperies or a piece of furniture. having greater fuel capacity.

3. This object ignites other furnishings and the temperature in the room builds up until "flashover" occurs, resulting in involvement of walls, floors. ceiling, baseboard, trim, doors, etc.

4. As parts of the structure burn through, adjoining compartments are ignited.

5. The fire spreads through the structure by successive breaching of walls, floors, ceilings, or by progressing up through floor openings, stairwells, etc.

6. By one means or another, adjoining structures may be ignited and, as they burn, they in turn may ignite other buildings.

7. Shortly after complete involvement of the initial building, the roof, floors, and perhaps walls collapse due to weakening and consumption of the structural members.

8. As the fuel in the initial structure is consumed, the fire decreases in intensity until the remaining fuel is largely in the form of glowing embers mixed with rubble.

The functions of the fire department fighting such a fire as that above change as the fire progresses from stage to stage, particularly if these functions have been unsuccessful at any stage:

1. If the fire has not progressed to flashover, the function is to extinguish the initial, incipient fire.

2. If flashover has occurred but the fire is confined to one or two compartments (or even to one or two floors) the basic functions are to:

    a. Extinguish the fire in the compartments.

    b. Prevent spread to other spaces.

3. If the building is largely involved, the primary function is to prevent spread to other buildings.

Implicit in the description of this breakdown is the belief (which is borne out by experience) that once several partitions have been breached by fire, extinguishment of the compartment fires is replaced by prevention of spread to other compartments. It appears that if several spaces are involved, firefighting activities concentrate on preventing further internal spread, until most of the fuel in the burning area has been consumed, and then on extinguishing the much less actively burning embers.

WARTIME EXPERIENCES

The large-scale air attacks of World War II, and the massive urban fires that they caused, presented the fire services with problems that were unanticipated and

created demands for their services that far exceeded their surviving capabilities. Although there are obvious differences between conventional and nuclear attacks on cities, the resulting fires are not unalike, at least qualitatively, and the experiences of the fire services with the large-scale fires of the war should offer some guidance in formulating concepts of operation for possible future nuclear attacks on cities of the United States. An excellent and comprehensive review of fire-service experiences and modes of operation in Germany during the war years has been prepared by Dr. Hans Brunswig, who was directly involved in the Hamburg fire defenses during the war. Much of the material in the following discussion is extracted from a recent English translation of that review (Ref. 4).

It appears that the essential differences between peacetime fires and those caused by conventional bombing are the high spatial and temporal concentrations (and large numbers) of fires and the large numbers of people who are unable (because of blast damage) or unwilling (because of fear of the external environment) to escape the dangers of the developing fire. As a result of the large numbers of fires, the fire services are unable to suppress or control all of the fires (or even a small fraction of them), and in order to accomplish as much as possible of their primary, lifesaving objective, they are forced to concentrate on rescue and relocation. In spite of the best efforts of the German and Japanese fire services during World War II, the death toll was staggering.

An indication of the size of the problem can be seen in the casualty figures. In the Hamburg fire storm, roughly 40,000 people died from direct or indirect effects of fire (Ref. 5), although the fire service is credited with saving from 3000 to 5000 through its rescue and evacuation efforts (and some 200,000 apparently survived without help). Another indication of the hazard to life in the large fires of World War II can be inferred from the ratio of deaths by fire to building losses due to fire. In peacetime, this ratio is in the order of magnitude of 1:100. In the major fires of the war, the ratio was typically in the range of 1:3 to 1:7, while in the fires that have been

described as fire storms (including the atomic bombing of Hiroshima) it approached 1:1 (Ref. 3).

During World War II. fire-service tactics changed as the war progressed. Although the first consideration was always given to saving lives. just as it always has been in peacetime. less effort was given to fighting fires that jeopardized the population and more to implementing rescue and escape from the threat. Within the German defense organization there were services. separated administratively from the fire service. that were charged with the responsibility of rescuing and untrapping people; but because most of the necessary equipment — particularly the ladders, hooks, and nets required for extricating people who were trapped in the upper stories of tall buildings — was part of the regular equipment of the fire services. who were often on the spot even before the air raid ended. the fire brigades accomplished a major part of the rescue work. even when fires were not involved.

As the air attacks grew in intensity and the fires grew in size. the fire services gradually abandoned firefighting as a general tactic: that is to say. its application became an adjunct to lifesaving activities. such as rescue and evacuation. In the areas that suffered mass fires and fire storms. all fire-service forces were deployed for aiding evacuation. In the Hamburg fire storm. water streams from the fire hoses were applied to escape routes to provide the protection of a "water street." Subsequent to that catastrophe. the main objective of the fire services in the large cities became the provision of "water streets" for the evacuation of mass-fire areas. It is estimated that during the period of heavy air attacks on Germany roughly 18,000 people. in Hamburg alone. were led to safety by the Fire Protection Service while protected by such devices as water curtains and water-soaked blankets. Although the concept was successfully applied in improvised ways in many isolated instances. a formal plan was apparently never put into practice successfully.

A major factor in the saving of lives from fires in the period following the Hamburg fire storm of July 1943 was the realization that mass fires cannot be

controlled and the implementation of prompt evacuation of areas threatened by uncontrollable fires. The fire hazard to shelter occupants was never considered in depth in improvising or constructing the air raid shelters in Germany.* Prior to the experiences with mass fires, it had been assumed that fire-threatened shelters could be evacuated without great difficulty in the rare instances when it would be necessary. Durï g the Hamburg fire storm, thousands of people were driven out of shelter and into the streets. Immediately after the fire storm, the President of the Hamburg Police Department distributed a pamphlet to the residents of the city giving instructions on when and how to evacuate shelters threatened by fire. We have reproduced it below.** Its pertinence to nuclear attack situations is worth noting.

> ### When is it necessary to leave the air raid [fallout] shelter under conditions of fire?
>
> The Air-Raid Protection Warden [shelter manager] must keep himself informed at all times of the progress of fires in the proximity of his house [shelter building]. He must do this by sporadically emerging from the shelter for personal observations. If a situation occurs wherein it is impossible to save the house [shelter building], and if it is determined that row and area fires are raging in the vicinity, the shelter area must be evacuated immediately. The danger of perishing in the shelter in such situations is usually so great that even though the only escape route may lead through burning streets, it must be taken. The area protection service community [local civil defense organization] must lay out advance plans that delineate possible escape routes and approximate facilities for protection (such as open spaces, parks, etc.). The escape route actually used will obviously be decided in the face of relevant dangers, and at the last moment. During the escape water-saturated blankets and other materials, if placed before mouth and nose and around the body, will afford adequate protection. In order to prevent the singeing of female hair, it is desirable to wrap damp kerchiefs around their heads.

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*In conducting the National Fallout Shelter Survey, which provides the greater part of the shelters currently available to the civilian population of the United States, little in-depth consideration was given to fire vulnerability either. A significant part of the OCD-sponsored fire research is now directed toward remedying this weakness, however.

**Terms corresponding more closely to present-day usage have been inserted in brackets.

Shortly thereafter. sections of the city that were considered to be particularly
vulnerable to fire were so designated and were surveyed for suitable fire-safe refuges
and promising routes of escape. The escape routes were marked with white arrows,
and the entrances of buildings were posted with notices which read: "The following
assembly areas have been assigned to the occupants of this house in the event of a
fire storm." According to Brunswig, "In cities, whose occupants had previously
experienced area fires. no subsequent casualties could be attributed to belated
shelter evacuation."

Section 4
OPERATIONS IN NUCLEAR EMERGENCIES

SPECIAL PROBLEMS ASSOCIATED WITH NUCLEAR ATTACK

There are three weapon effects that produce significant initial damage of importance to fire-service operations: thermal radiation, air blast, and prompt nuclear radiation. Damage produced, generally, is less at greater distances from ground zero. Close to the point of detonation, intensities are very high, and all forms of damage are expected. However, casualties produced by prompt nuclear radiation from megaton-yield weapons would seldom occur at ranges where survival of blast effects would be expected.* Therefore, we can limit our principal concern to blast and thermal effects.

Some areas beyond the range of initial ignition effects may be susceptible to the spread of fire from other areas, and even though side effects such as blast or fallout may be absent, the capabilities of the firefighting organization could still be overwhelmed. Another possible case of concern is in those locations in which the only weapon phenomenon present is fallout radiation of a level high enough to force all persons into fallout shelters. Although in this case, fires may not be present initially, fires of other origins, e.g., from spontaneous combustion, electrical short circuits, or overheating, and vermin activity, lightning, etc., will undoubtedly occur over a period of time. Such a possibility raises two problems: reporting and control. Since people, the normal source of information as to the presence of fire, are not necessarily present, new concepts of detecting and reporting fires may be required. And since the environment presents a radiological hazard, new techniques and concepts which permit fire control without undue risk to personnel may be required.

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*This generalization applies to a population in structures of types normally encountered. It might not be true for a shelter that is blast resistant.

In the range of distances from ground zero, between near-total destruction and inconsequential damage, lie the demands for fire-service action and a broad spectrum of environmental constraints on fire-service response. The following are examples of the special problems associated with nuclear attack:

1. Demands that far exceed the capabilities of the fire services, both in numbers of fires and numbers of people threatened by fire and other hazards.

2. Losses in personnel, equipment, essential resources such as water for firefighting, mobility, visibility*, and the means of assessing the threat and communicating information relating to it.

3. Constraints imposed by blast damage and radiological hazards.

4. Psychological factors such as emotional shock, disorientation, and panic.

Both thermal and blast effects generally occur in the same areas. Typically, the urban target would sustain two wide bands of combined blast— thermal damage: (1) moderate-to-heavy structural damage by air blast, high initial incidence of fires, and significant fractions of the survivors in trapped and injured states, and (2) light-to-insignificant structural damage by blast, scattered fires, and few casualties. The dividing line between the two would typically be determined by peak overpressures in the 3-1/2- to 5-psi range (Ref. 6). At distances beyond about the 1- to 2-psi range, there would be little significant damage and few initial fires or casualties.

As a first rough approximation, then, we can say that virtually all of the demands for fire services will lie between the 1- and 20-psi contours. However, the large number of fires and large amounts of debris in streets impeding mobility coupled with the probable loss of water pressure would typically limit successful control of fires to areas well outside of the 5-psi overpressure range.

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*Dust raised by blast effects could seriously limit damage appraisal by visual observation for a period of a half an hour or more (Ref. 4).

Because the weapon effects are so widespread, the surviving fire services within directly affected are : would ordinarily have to try to cope with local demands without outside help. If they were unable to control the fires and/or provide protection from other hazards, they would then have to initiate and implement alternative actions to extricate survivors from the threat, such as remedial movement of shelterees or complete evacuation of the area; but the distances involved and the hazards imposed by the environment would in many situations make the latter alternative very unrewarding, if not futile.

It can be seen that there is a very real need for preplanned strategies to give the fire services the maximum possible advantage through quick evaluation of the situation and realistic and prompt response.

Constraints on Operational Feasibility

The point has been made that some traditional fire-service operations are infeasible under some circumstances following massive incendiary attack and that effective accomplishment of lifesaving objectives is critically dependent upon early recognition of these circumstances by those in command and a prompt commitment of forces to the remaining alternatives. Therefore, a knowledge of the limits of operational feasibility is a basic prerequisite to preattack contingency planning as well as an essential element of command decision-making following attack. For our present purposes, however, an understanding of the factors which limit the feasibility of various operations is required to allow us to assess the suitability of alternative tactics for different operational situations.

Feasibility of various lifesaving and life-support operations is constrained by combinations of weapon-effect loading, i.e., blast, fire, and fallout radiation. For a large part of the expected modes of weapon delivery and conditions of burst, there is a rough correspondence between blast loading and fire loading, and for many planning purposes the fire threat can be crudely predicted from air-blast overpressures.

It should be kept in mind, however, that this is not the case for all credible attack situations. In fact there are substantial differences to be expected in fire threat for a given blast load between surface bursts and low air bursts. Moreover, differences in the characteristics of urban targets significantly affect both blast and fire responses.

For situations where one or more of the three weapon-effect loadings are very high, all emergency operations become infeasible. At lower loadings some operations are feasible while others cannot be effectively carried out or must give way to more effective actions. A distinction must be made between lifesaving and life-support activities, partly to indicate that a higher priority is given to the former, but also to indicate that many life-support activities, such as firefighting to save property, are often infeasible under conditions where lifesaving activities can still be accomplished effectively.

Some of the feasibility limits are not uniquely determined by weapon effects. The inherent capability and surviving strength of the fire services can also affect the limits of operational feasibility. However, for the present we will make the simplifying assumption that, for practical purposes, limits can be established on the basis of weapon effects alone.

Our purpose in the following discussion is to present the background information on weapon effects that will serve to delineate operational feasibility as well as to guide the formulation of preattack plans and both the recognition and prediction of operational constraints following attack.

Blast Effects as a Constraint on Feasibility

Blast effects provide one limit to the feasibility of fire-service operations. In the extreme, where overpressures are very high (20 psi and over), collapse of most structures and high population mortality is the expected result. In areas suffering these and somewhat lower overpressures (the 5- to 10-psi range), many traditional fire-service operations would be either impossible or ineffectual because of (1) the

4-4

loss of water for firefighting. (2) impassible debris levels in the streets. and (3) the relatively low survivability of the victims combined with the large manpower requirement for the entrapping of survivors from collapsed structures. In areas experiencing much lower overpressures (less than 1 psi), essentially no demands would exist initially.

Methods have been developed at URS and elsewhere for the prediction of structural damage (Ref. 7), debris levels (Ref. 8), and damage to equipment and utilities (Ref. 9). Feasibility constraints from blast effects alone can be estimated by the application of these methods. Blast-casualty curves have been developed by SRI (Ref. 10) based on casualty functions developed by Dikewood Corporation (Ref. 11). Examples of these will be presented along with the discussion of performance relationships in the next section.

Fallout as a Constraint on Feasibility

The radiological hazard produced by fallout can be significant anywhere within the zone of direct damage as well as far beyond its limits. However, in the current Concept of Emergency Operations (Ref. 1) it is considered to be a constraint on essential fire-service operations only in the virtual absence of the more certain threats to survival such as those from fire. Accordingly, the doctrine for fire-service action is to respond to the lifesaving demands in spite of the radiological environment. Only in cases where (1) there is no immediate local threat to survival that the fire services can alleviate. and (2) other demands are so remote as to preclude effective response should the fire services cease operations and remain in shelter. A third contingency. i.e.. when the fallout level is high (dose rate, over 50 R/hr), might inhibit firefighting. but Ref. 1 envisages the possibility of continued firefighting operations even at the cost of firefighters.

Fire as a Constraint on Feasibility

When everything is considered. it appears that, in those direct-damage areas in which a significant fraction of the population can be expected to survive the initial impact of nuclear attack. the main determinant of the feasibility of fire-service operations is the "controllability" of the fire situation. Factors relevant to the assessment of fire controllability are discussed in the following paragraphs.

Overall Urban Fire Threat

Simultaneously with the appearance of the fireball, fires are ignited to distances of many miles from the burst point. Most of these fires are quite small and many of them "go out" without developing into a fire of destructive magnitude, but the persistent ones soon grow into building fires. The passage of the blast wave changes the fire picture by extinguishing some of the incipient fires, damaging structures and rearranging fuels to either enhance or inhibit the growth of destructive fires, and by generating secondary fires. The extent of blast interaction depends on many factors. but in a large proportion of the credible cases, fires will extend to the limit of significant blast damage and beyond.

Within about half an hour following the detonation, destructive fires will be well developed within many of the structures left standing. Areas of high building density suffering a high initial fire incidence (such as one in two) have the potential of becoming fire-storm areas, possibly within the first half hour after attack. In areas of high fire-spread potential, mass fires may develop within the first hour or two and spread uncontrollably for many hours, possibly days, even though the initial fire incidence was light. In areas of low fire-spread potential, fires will typical'v spread slowly and be limited to within the block of origin or several blocks from that point and will burn themselves out in a few hours except under windy conditions, when they may spread for long distances in the downwind direction.

An example drawn from interim results of Work Unit 2538C (Ref. 12) will serve to illustrate the nature of the threat.[*] Figure 1 depicts the initial fire distribution in a residential urban area following a megaton-yield air burst. The example given is for a hypothetical area made up of blocks containing 20 structures each. It is of interest to note:

1. The shallow nature of the fire-density gradient (expressed as the fraction of buildings burning).

2. That nearly every block has one or more fires out as far as the distance at which only about 10 to 20 percent of the structures are burning (suggests importance of short-range spread in fire development in this area).

3. That very few blocks have a fire about a mile or two farther out (suggests importance of long-range spread in fire development in this area).

Figures 2 and 3 show how fire spreads within a block by short-range spread. Figure 2 is an example of a single row (representing an idealized case for residential areas) containing 12 buildings. Only about twice the number initially ignited are burning actively at any one time -- shortly after the first spread generation. Figure 3 is an example of a cluster of 12 buildings (representative of highly built-up areas). In this case a large fraction of the buildings are actively burning at one time. This is the situation that could generate a firestorm. Note that only 20 percent of the buildings were initially ignited. We might conclude that in heavily built-up areas the uncontrollable fire situation could extend to the 20 percent fire initiation distance or beyond (typically something like the 2 to 3 psi line for an air burst).

But what about the areas farther out? Figure 4 shows the development of a fire front in the area of less than 10 percent initial fires.[**] This front has the

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[*]Methods of fire-threat analysis are given in detail in the final report of Work Unit 2538C (Ref. 12), which is currently in preparation.
[**]The checker-board patterns in the figure illustrate for locations on either side of the front the density of blocks having one or more fires.
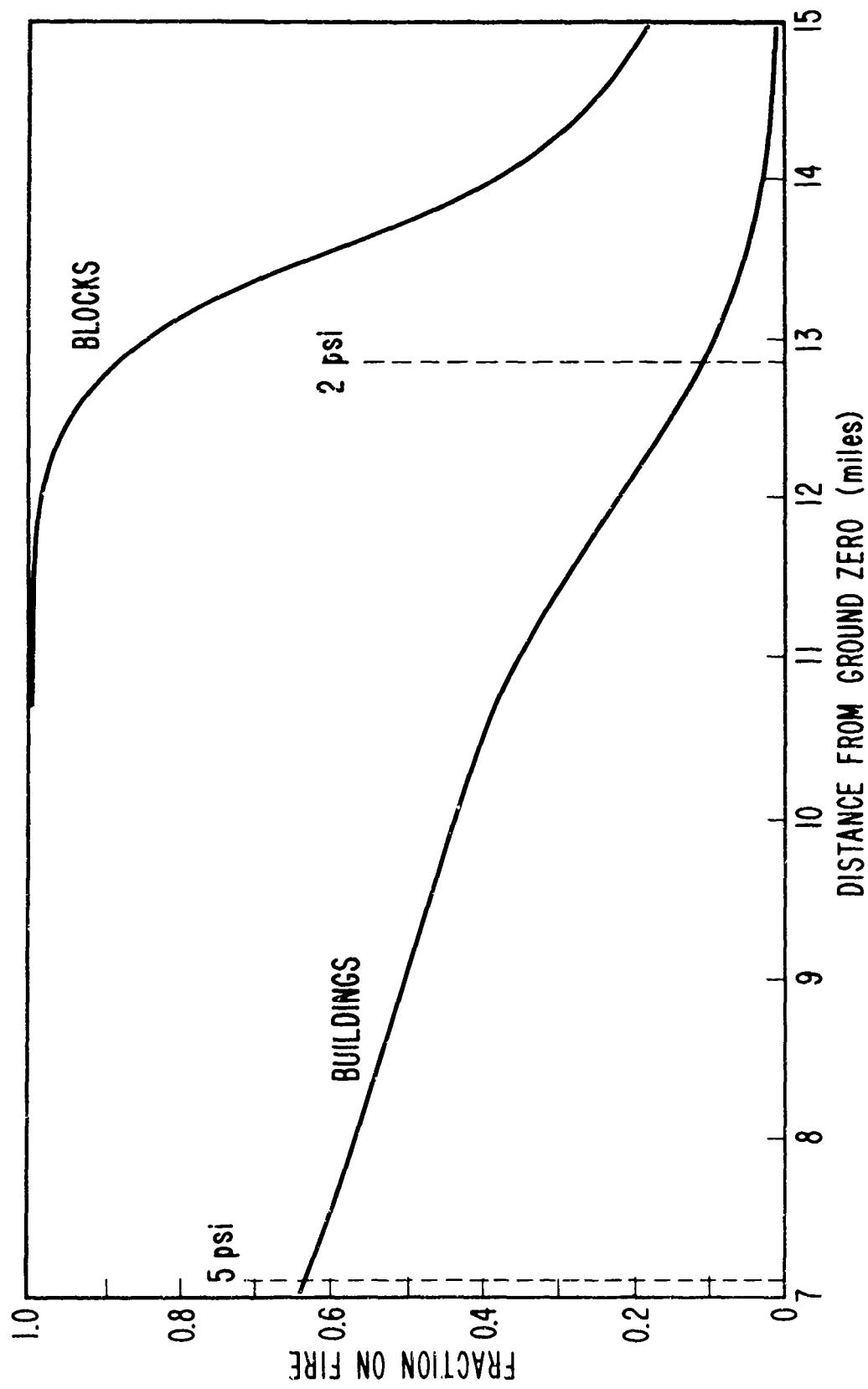
Fig. 1. Example Initial Fire Distribution in Blocks Containing 20 Buildings Each (Approximately H to H + 30 min)
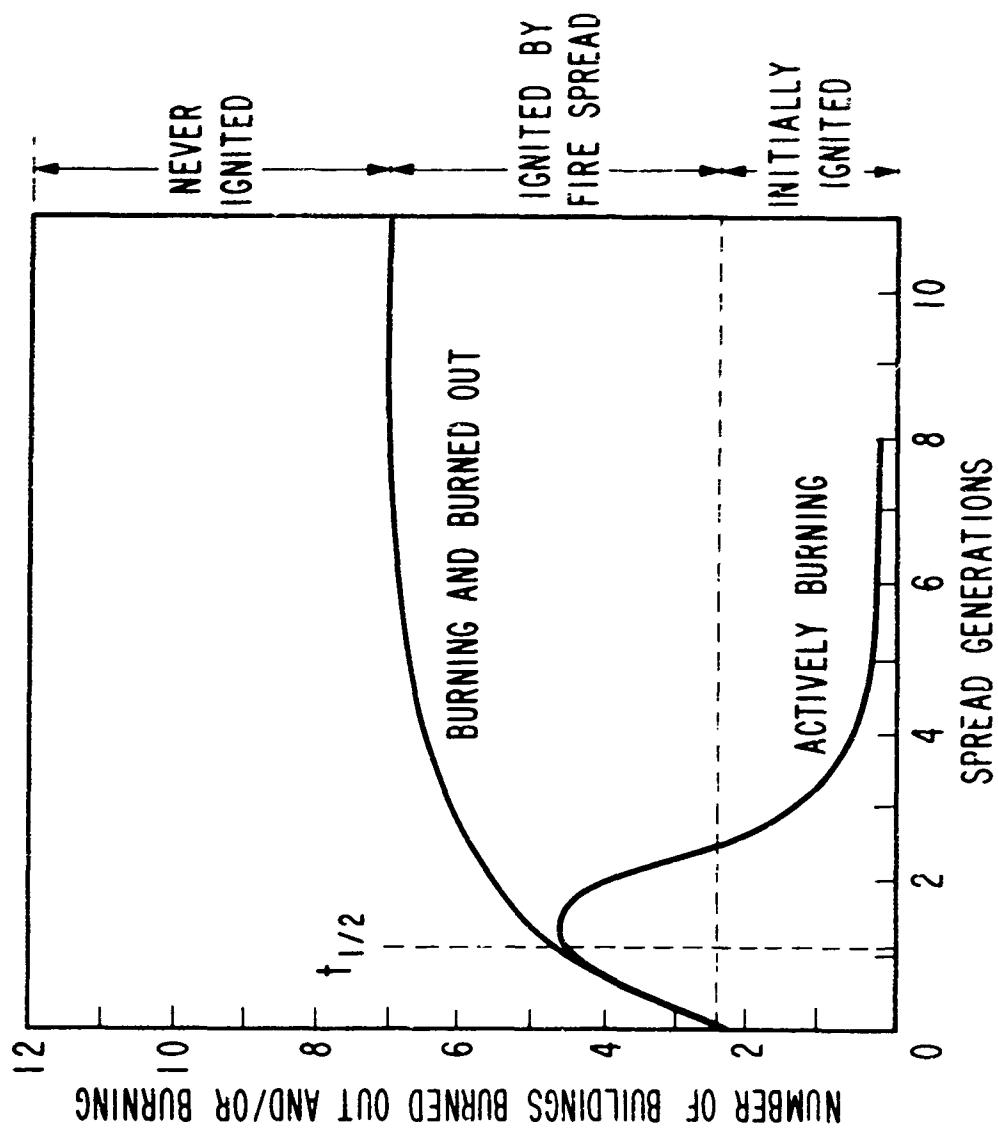
Fig. 2. Example History of Fire Spread Along a Row of 12 Buildings
Probability of ignition = 0.2   Probability of spread = 0.7
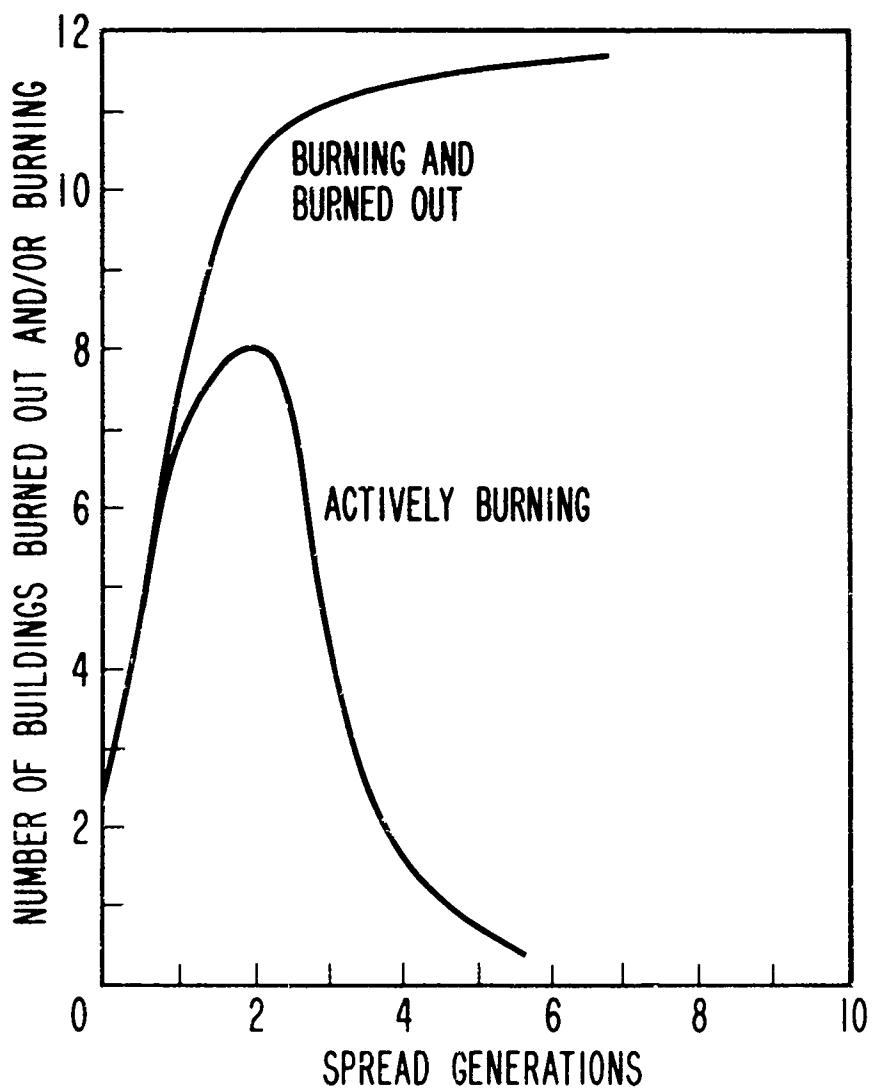
Fig. 3. Example History of Fire Spread Through a Cluster of 12 Buildings
Probability of Ignition = 0.2 Probability of spread = 0.7

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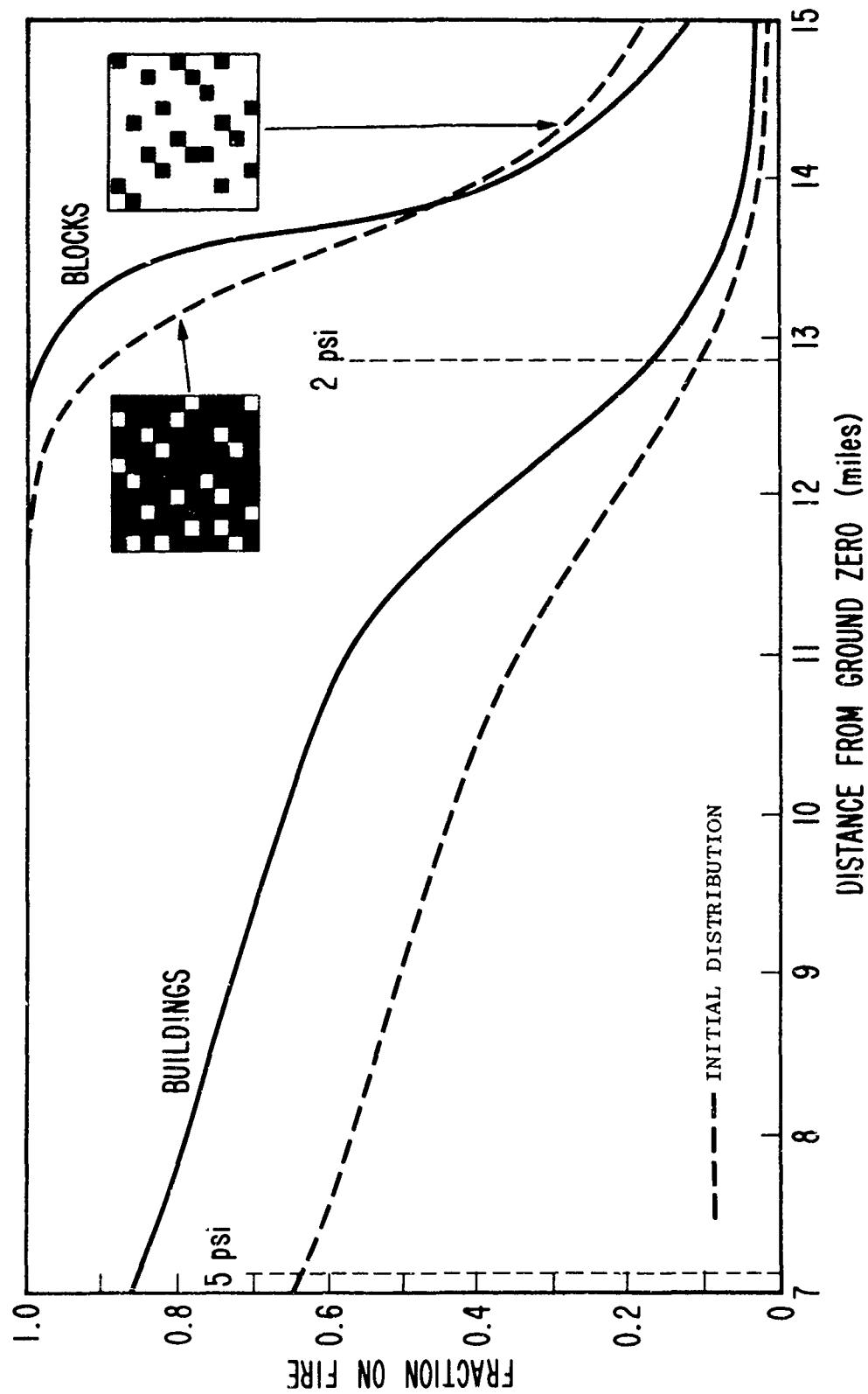
Fig. 4. Example Fire Distribution After First Spread Generation Showing the Development of a Fire Front (Approximately H + 1 hr)

potential of moving into areas of few initial fires and becoming a conflagration if the long-range spread potential is large. Figure 5 shows the expected average spread distance (in blocks)of such a fire front for different long-range spread probabilities. The potential threat is quite small until the probabilities approach about 0.4, but for larger values spread becomes indefinitely large. Therefore, in areas having a high potential for long-range spread, an uncontrollable fire may eventually range far beyond the areas of high initial fire incidence.

Interim guidance for evaluation of the fire-threat by long-range spread can be gotten from a rough discrimination of areas of high and low fire-spread potential such as is provided by the Conflagration Potential Methods developed by Gage-Babcock (Ref. 13); but methods such as those alluded to above, when they are fully developed, will offer a more complete and reliable approach. At that point, we will be in a position to decide which fire breaks are promising for making a stand against a moving fire front.

The Fire Threat to Fallout Shelters

One of the current plans for fire-service deployment in a nuclear emergency is keyed to the system of shelters designated by the National Fallout Shelter Survey, with fire-service units assigned to preattack locations at shelter buildings for the purpose of (1) taking advantage of the shelter afforded, (2) being in direct contact with elements of the civil defense structure, and (3) protecting the fallout structure and its occupants from fire. This is the San Jose, California, system, not necessarily widely adopted nationally. In an area suffering the direct effects of a nuclear attack, the natural immediate-post-detonation response of the surviving forces would be to search for fires within the assigned shelter building and to extinguish them promptly before they become a significant threat to the security of the survivors in the shelter. If they should be unable to successfully suppress the fire so that it becomes a clear threat to the survival of the shelter occupants, or if after successfully combating the
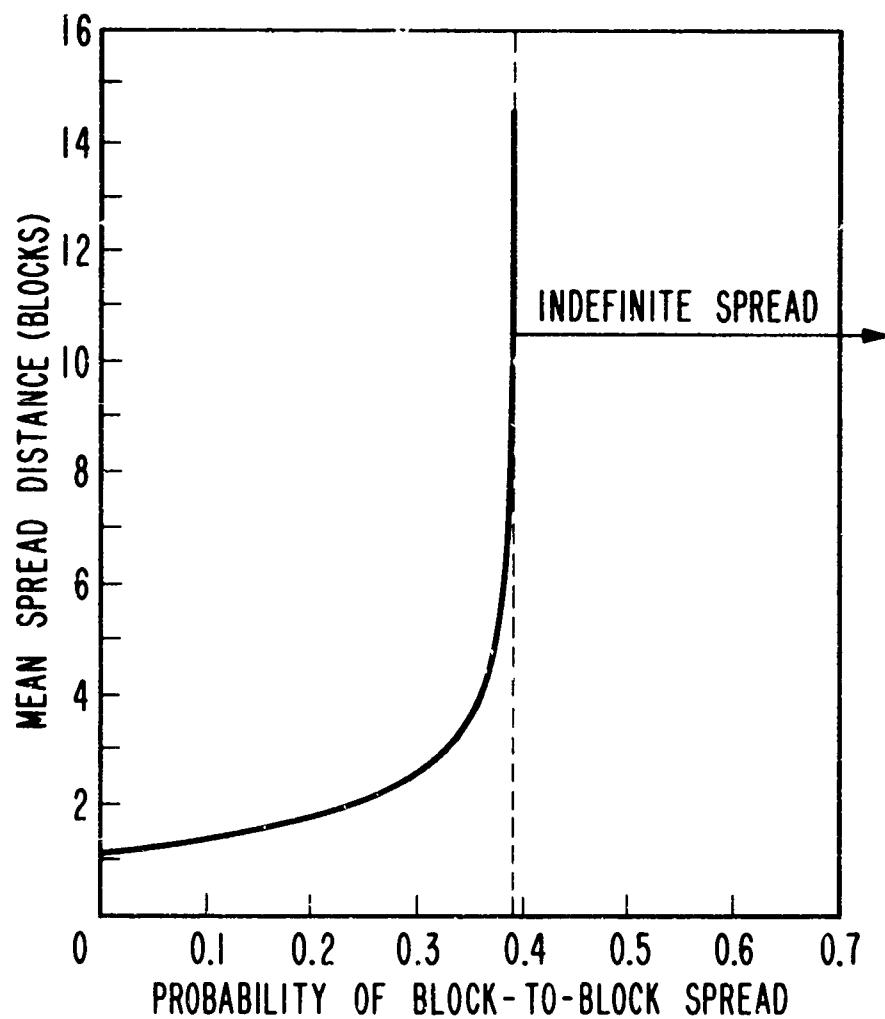
Fig. 5. Expected Ranges of Fire-Front Spread as Determined by
Block-to-Block Fire-Spread Probabilities

fire in the shelter structure an appraisal of the local (or even remote) fire situation indicates that the shelter will eventually succumb to fire despite their best efforts, remedial relocation or evacuation should be promptly ordered. The fire-service force would then turn its attention to aiding in the evacuation or to the needs of a nearby shelter or other concentration of threatened survivors in a way consistent with the greatest demand and the best prospects for saving the greatest number of lives. Two examples of situations of this sort have been studied during the course of this research. The results of these case studies are presented in Appendix A of this report.

A vital factor determining the success of fire-service response to the fire threat to shelters is the prompt and accurate appraisal of the threat. Many factors are involved, including the characteristics of the shelter building itself, the characteristics and proximity of neighboring structures, the characteristics of surrounding urban areas, the numbers and locations of initial fires, and weather conditions, especially the speed and direction of the wind near the ground. As much as possible the fire vulnerability of shelters should be ascertained in advance and routes to fire-safe shelter should be worked out and displayed clearly within the shelter.

The fire vulnerability of a shelter building should be considered for several different situations:

1. Direct initiation of a fire in the structure

2. Direct initiation of a fire within the same block (or other concentrated group of buildings) as the shelter structure

3. Long-range spread of fire to the vicinity of a shelter building not threatened by immediate fire effects

Some structures, because of their construction and/or large separation distances from adjacent structures, are vulnerable to fire effects in situation 1 only. These are

the structures for which thermal countermeasures would have the biggest payoffs, i.e., they can be hardened thermally with modest investments of cost and effort to provide safe haven from both immediate and long-term incendiary threats. The preattack determination of a structure's fire susceptibility can be made by a fire protection engineer having knowledge of nuclear-postattack environmental conditions (Ref. 14).

For all other structures it is important to consider the vulnerability for all three situations mentioned above. It will be noted that situations 1, 2, and 3 have the sense of decreasing immediacy of hazards. That is, fire initiated within the shelter building has the potential of either claiming lives or forcing evacuation of the shelter within minutes after the attack, whereas the spread of fire from within the block could take any where from about a half hour to several hours. and the spread of fire from more remote areas, hours to days. The implication of these differences in time for remedial movement is obvious.

The prediction of fire threat to shelter buildings for the conditions resulting from a specified nuclear attack is basically the same as that given earlier for the overall urban fire threat, except that a more specific approach can and should be used which takes into account the detailed characteristics of the structure and its neighborhood rather than one which uses "class-average" characteristics of an entire urban area.

CONCEPTS OF OPERATION IN NUCLEAR EMERGENCIES

Recognizing that the overall demands for emergency services far exceed the capabilities of existing forces and resources (even without being degraded by attack), planners of emergency operations have sought ways of optimizing performance. A basic question for many years has been — is it better to disperse the emergency operating forces well beyond the outskirts of a city to minimize their losses, or risk loss to gain time by deploying the forces to areas where initial demands are expected

to be high? These two contrasting ideas are embodied in the so-called "outside-in" and "inside-out" concepts of preattack deployment. In the early postwar years when strategic nuclear weapons were still measured in kilotons, the former concept was particularly attractive because of the limited range of weapon effects. This concept has lost favor to the "inside-out" concept as weapon yields have incre d; however, neither can be said to be clearly established as a preferred posture for fire services by studies to date.

In favor of the "outside-in" concept we have such factors as minimal degradation of force and mobility which would provide for full, coordinated activity at peripheral points (in the 1- to 3-psi overpressure range), where fires may be most susceptible of control. It would minimize the commitment of forces to untenable situations, reduce the chances of fire spread into initially undamaged areas, and aid the evacuation of ambulatory survivors of the more heavily damaged areas. Against the concept we have factors such as virtual abandonment of the initially surviving population and resources of the more heavily damaged areas or even of the political entity itself.

In favor of the "inside-out" concept are such factors as quick response to points of maximum demand and the very real possibilities of maintaining "islands of resistance" in the midst of otherwise untenable situations, from which successful evacuation is doubtful. The effectiveness of fire-control actions in areas of initial fire will be strongly dependent upon how rapidly the action is initiated. It is fair to say that the local battle may be won or lost within the first 20 minutes after the detonation. Fire services committed to protect survivors and resources in areas of high initial fire incidence must be prepared (through preplanning and training) to make a rapid (almost automatic) assessment of the threat and to respond appropriately without delay. The fire situation can change rapidly with time necessitating continual reappraisal and the ability to recognize the need for a change in tactics at the earliest possible time. The successful evacuation of an untenable situation will often depend

entirely on promptly realizing that the threat exceeds the control capabilities and turning attention to effecting the evacuation while there is still time.

The main disadvantage of the "inside-out" concept is that it maximizes the chances of degradation of the already limited fire-service capability. Loss of trained personnel by injury, trapping, or death is serious enough in itself, but fire-service units located in areas exposed to moderately high blast overpressures would suffer not only personnel casualties but losses in equipment, mobility, and available water as well, degrading their capabilities to little more than that of self-help brigades.

With reasonable warning time, preattack operations can and should be performed according to a previously established plan. A number of preattack actions could be taken which would reduce the fire damage resulting from attack. These include implementing thermal radiation countermeasure procedures, securing hazardous utilities, distributing self-help extinguishers, building and filling emergency reservoirs of water, etc. With attack imminent, all fire-service personnel, off duty as well as on, would report to duty stations. The previous discussion of the general concepts of emergency operations suggest that there are two rather different preattack deployments that appear to have merit: (1) fire-service units occupying locations close to (or in) major fallout-shelter buildings and buildings housing vital resources and (2) fire-service units dispersed outside of the heavily builtup central area of the urban complex* (Ref. 15). The first, which is compatible with "inside-out" concept of operations, would correspond to the general strategy of risking a heavy loss in personnel, equipment, and mobility to be in position to service the critical demands immediately. The second posture, which is of the "outside-in" sort, corresponds to the strategy of retaining a high level of undegraded force and mobility to move quickly to the sectors of greatest demand. This posture is perhaps more compatible with the "movement-to-shelter" population posture or the warned-resident-population posture than with the current NFSS plan, but its advantages in any case are attractive.

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*Dispersal could be along major thoroughfares or to multipurpose staging areas as described in URS 672-10.

In actual practice the deployment is not an either/or matter. That is, there is ample room for other options, involving a blend of the approaches just discussed, or others that reflect the impact of various forms of pre-attack preparedness for the reduction of vulnerability. For example, use of thermal screening smoke shifts the location of the 20″ ignition area.

The use of thermal countermeasures would generally have the effect of reducing the range over which initial ignitions would occur and reducing the number of ignitions at any one range. The extent of this reduction would depend on the extent and effectiveness of the countermeasures employed. For the "inside-out" concept of operations, the disadvantage of maximized degradation would still be present since damage occurs chiefly by blast. Those remaining forces, however, face a much less formidable demand situation. Areas which, without countermeasures, would be untenable may now be saved from fire, especially by fire forces which can initiate actions rapidly by being at hand.

For the "outside-in" concept, the disadvantage of abandoning the area would still be present. The minimally degraded forces would still be very useful where fires may be most susceptible of control, especially since there would be a smaller number of such fires. A new disadvantage would be the need to travel further to reach such fires (due to the reduced range of ignitions) with the complications of debris, since these fires are now closer to ground zero.

Whatever deployment strategy is used, the responses of the fire services after the attack will be determined in varying degrees by conditions resulting from the attack which are largely unpredictable and over which the fire services have no preattack control. For example it cannot be foreseen with any certainty where the detonation will occur, how large the explosive yield will be, and whether there will be more than one detonation close enough to the metropolitan area to inflict significant damage and hazards on it. Thus some of the fire-service units may find themselves

in areas of direct effects and high local demand while others may not, irrespective of the deployment strategy.

Because of the uncertain nature of the distribution of damage and residual hazards throughout urban areas, fire-service plans for emergency operations must be prepared for all major contingencies, ranging from no effects at all to the limit of operational feasibility, and provision must be made for prompt, accurate assessment of threats, demands, and degradation of capability so that effective and realistically chosen responses will result without costly delay when attack occurs.

The current Concept of Emergency Operations (Ref. 1) prescribes nine basic operating situations derived from combinations of three fallout levels (including the virtual absence of fallout radiation) with three fire-threat levels (including no fire threat). The basic doctrine is that fallout radiation is to be considered as a constraint on essential and urgent operations only in the virtual absence of the more certain threats to survival, such as fire. Inasmuch as fire control and protection of survivors threatened by fire are essential and urgent demands, it is only in the areas of insignificant fires — those somewhat remote from the impact area — that fallout determines the operational objectives of the fire services. This reduces the number of contingencies to four, as indicated in Fig. 6.

Fig. 6. Primary Objectives of the Four Major Threat Contingencies

In the areas of negligible fire threat. then, there are two threat contingencies appropriate to fire-service operations:

CONTINGENCY I - "FREE"

BASIC OPERATING SITUATIONS - $\begin{cases} \text{NEGRAD} \\ \text{LORAD} \end{cases}$ NEGFIRE

PRIMARY OBJECTIVE - Aid Impact Zones

SECONDARY OBJECTIVE - Maintain Life-Support Facilities

CONTINGENCY RESPONSE

Preattack Preparation	Emergency Activity
• Plan fire patrols	• Assess fire threat
• Designate routes for mutual aid	• Patrol locally for delayed threats
	• Optimize shelter utilization
	• Provide aid to impact areas

CONTINGENCY II - "PINDOWN" RADIATION

BASIC OPERATING SITUATION - $\begin{cases} \end{cases}$ HIRAD - NEGFIRE

PRIMARY OBJECTIVE - Secure Maximum Sheltering for Population

SECONDARY OBJECTIVES - Maintain Life-Support Facilities: Conserve Shelter Resources

CONTINGENCY RESPONSE

Preattack Preparation	Emergency Activity
• Plan for prolonged shelter stay and for essential out-of-shelter operations	• Assess fire threat
• Implement for aid in decontamination	• Seek shelter and cease all but absolutely essential operations (e.g., responding to delayed fire threats. providing necessary additional shelter capacity for impact-zone evacuees)

In areas having a fire threat to survivors or survival resources, the basic distinction operationally is between controllable and uncontrollable fires. Therefore, there are two more threat contingencies for which the fire services must plan. The objectives and planned responses of fire services in these two threat contingencies may be summarized as follows:

CONTINGENCY III - CONTROLLABLE FIRES

BASIC OPERATING SITUATIONS - $\left\{ \begin{array}{l} \text{NEGRAD} \\ \text{LORAD} \\ \text{HIRAD} \end{array} \right\}$ - LOFIRE

PRIMARY OBJECTIVES - Control Fire; Protect Shelters from Fire

SECONDARY OBJECTIVE - Protect Life-Support Resources

CONTINGENCY RESPONSE

Preattack Preparation	Emergency Activity
• Implement maximum self-help capability	• Assess fire threat
• Designate potential lines of defense	• Use self-help teams to suppress ignitions
	• Establish fire-defense lines at appropriate fire breaks
	• Suppress fires that exceed self-help capability, but only if they pose an imminent threat to survivors or life-support resources

CONTINGENCY IV - UNCONTROLLABLE FIRES

BASIC OPERATING SITUATIONS $\left\{ \begin{array}{l} \text{NEGRAD} \\ \text{LORAD} \\ \text{HIRAD} \end{array} \right\}$ - HIFIRE

PRIMARY OBJECTIVE - Protect and Relocate Population at Risk

SECONDARY OBJECTIVE - None

CONTINGENCY RESPONSE

Preattack Preparation	Emergency Activity
• Establish area and shelter fire vulnerability	• Assess fire threat
• Designate relocation sites and routes	• Protect low-risk shelters from fire
	• Implement relocation from high-risk shelters
	• Rescue lightly trapped survivors
	• Evacuate area

For maximum effectiveness, the fire-service unit cannot be expected to operate independently. The need for information about the overall picture of threat and demand and for support from other emergency services e.g., medical treatment, debris clearance, transportation of rescuees. etc.. requires a close coordination of the fire service's activities with those of other agencies through a higher echelon of control, such as the emergency operations center (EOC) of the civil defense organization. There might very well be situations, however, in which a fire service unit would, at least temporarily, be out of contact with higher echelon control. Under these circumstances, it would have to act effectively on its own, which it could do only if the local commander were able to make prompt and accurate appraisals of the local situation from limited information.

In either case — where the overall activities are coordinated through a higher echelon command or where a unit commander must act independently — the effective performance of damage control and rescue will depend upon prompt and accurate appraisal and continual reappraisal of the fire situation. A practical approach to developing a concept of fire-service organization and coordination is to view an urban complex as consisting of contiguous areas of operation for individual fire-service units. These areas could be established relative to normal jurisdictional boundaries

or to boundaries around points of emergency deployment that represent the maximum range a fire-service unit might be able to cover in response to postattack demands. Either way, the operational area would, in general, be small compared to the range of weapon effects. Higher echelon control would be based on assigning to each of the operational areas a damage classification indicative of hazards, demands, anticipated future threats, obstacles to action, and feasible courses of action. The assignment would be derived from a damage appraisal based on various sources of information, fragmentary at first but improving with time as unit commanders are able to assess and report local conditions. The development of a useful and practical set of such damage/demand categories is an important objective of civil defense research. The nine basic operating situations described previously is an example that appears to be operationally practical. A discussion of some interim rules for guidance of fire-service response based on the nature of the fire threat (its imminence and whether or not it can be controlled) has already been presented. (See Overall Urban Fire Threat and Fire Threat to Fallout Shelters.) The basic assumption is that fire conditions in some areas following nuclear attack, coupled with losses in resources and mobility, could be so extreme as to preclude any effective fire-fighting and any but the most expedient rescue activities, regardless of the preattack strength and composition of the local fire service. These rules and their corresponding threat contingencies or damage/demand categories are intended to be of use at either the local or higher echelon level, because there is a need for appraisal and decision at both levels. It is quite conceivable, for instance, that a city block, a group of blocks, a single building, or a group of buildings containing a large sheltered population and/or life-support resources might be saved by concerted fire-service action in an area which otherwise is burning beyond control. It would be a mistake to evacuate such a situation, thereby abandoning the resources and needlessly exposing the population to either potential or certain hazards. Thus it would appear that, in areas of generally uncontrolled fires at least, the judgement as to whether the local fire threat is

controllable might have to be made at the local level. However, it must be recognized that the unit commander under such circumstances could well have a very limited view of the overall situation and might be unaware of long-range circumstances that promise to make his situation untenable. The importance of higher echelon control is obvious in such cases.

Section 5
PERFORMANCE RELATIONSHIPS

In order to quantitatively evaluate performance of the fire services. a series of relationships must be available which describes the interactions of resource expenditure (in terms of personnel. time. and material) with demands and accomplishments. Some of the required relationships are available from previous research. but may be inappropriate to fire services operating under nuclear-attack condition.. where resources must be conserved for the most critical demands, as opposed to peacetime situations, where resources are seldom inadequate.

As an example, IITRI indicates (Ref. 16) that the water usually delivered by fire services during a peacetime fire is many times that actually needed. This is also true of the number of pieces of equipment responding to an alarm. Much of the apparatus, although costly and sophisticated, merely serves the firemen as transportation. During overhaul*, the number of men used may be related more to the number available than to the number needed. The point is not made here as a criticism of fire department practices, but as a warning to the analyst who would apply peacetime operational data to wartime situations.

Fire service activities can be subdivided into three main groups: preattack preparations. fire-control functions, and "rescue" (including remedial movement) functions. The following lists cover each of these groups:

I. Preattack Preparations

    A. Fire prevention

    B. Thermal countermeasures

    C. Training of nonprofessional auxiliaries

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* "Overhaul" is the term used to describe the actions taken after the fire has been brought under control to assure that it will not start up again. A major part of the total effort is given to overhaul in peacetime fires.

II. **Fire-Control Functions**

   A. Search for fire

   B. Assess long-range threat

   C. Deploy or redeploy forces

   D. Extinguish ignitions (up to flashover)

   E. Suppress room fires (up to penetration)

   F. Suppress building fires (up to total involvement)

   G. Exposure control (including firebrand patrol)

   H. Demolition and backfiring

III. **Rescue Functions**

   A. Direct (or lead) ambulatory survivors to safe refuge

   B. Provide "water curtain" protection for evacuees

   C. Remove obstacles in routes of evacuation

   D. Provide transportation for evacuees

   E. Remove or release trapped survivors

   F. Provide first-aid medical assistance

In the following sections we will be considering postattack activities only. The various preattack preparations should have significant effect on the postattack fire problem, but we are concerned here with fire-control and rescue functions in the postattack period only.

FIRE-CONTROL ACTIVITIES

Performance relationships have been studied by quantifying the fire problem without control and then estimating the action required (effort and resource expenditure, equipment requirements, etc.) to gain control at different times. The type of information needed includes the time variation of fire growth, intensity, spread, etc.

Search for Fires and Survivors

A limited number of tests were conducted during the report period to determine the time required to search a building for ignition points and/or survivors. A walk-through search was made in buildings of several occupancy types having various compartment sizes and fuel distributions. Search times were recorded for large, open shop areas. partially compartmented shops. storage areas, and office areas. A walking rate of about 190 ft/min could be maintained while observing conditions 30 ft on each side. The same areas could be searched at a rate of 270 ft/min while observing conditions 20 ft on each side. The search-time data for both cases were in good agreement. A plot was made (Fig. 7) showing the search time for 10,000 sq ft as a function of compartmentation. The results agree quite closely with fire search data obtained by IITRI (Ref. 17), in which it was concluded that for 175 floor plans taken from a shelter building survey, the search time varied from 2 to 10 min for each 10,000 sq ft of floor area.

The actual time required for search depends, as shown above, on the floor area and compartmentation of the building involved. This would be so for a building experiencing no structural damage. It is evident that the presence of debris in halls and stairwells or damage to doors and doorways can substantially increase the required search times.

Extinguishing Initial Fires

Firefighting activities during the first half hour after the attack are especially important for a number of reasons. It is during this period that initially ignited rooms will flash over and become fully involved in fire. Fires which can be extinguished prior to flashover will require considerably less manpower, professional competence, specialized equipment. and water than fires for which flashover has occurred. It has been demonstrated and reported by IITRI in Ref. 16 that small self-help teams using
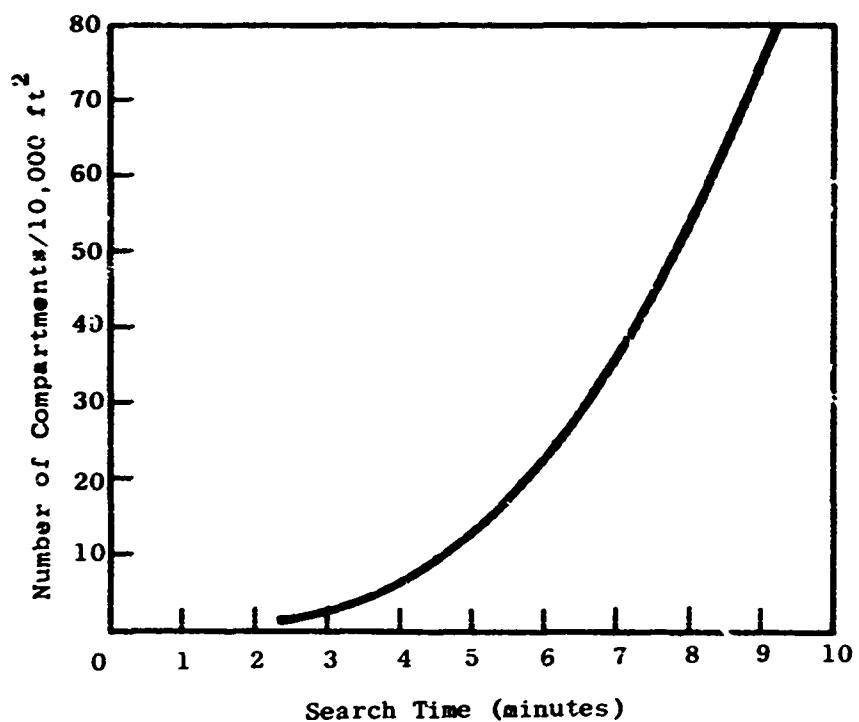
Fig. 7. Search Time vs Number of Compartments per 10,000 ft^2 of Floor Area

portable extinguishers are able to handle room fires up to a point just prior to flashover. Figure 8 presents this information in the form of probabilities of room flashover and extinguishment versus time.

The time required by self-help teams to suppress fires is also reported in Ref. 16. Depending on the type of fuel unit and the extent of involvement, the suppression time ranges from negligible to about 1-1/2 min. In addition, Ref. 16 states that the time differential considered necessary for a self-help team of two men to suppress one fire and to reach another is 5 min. Self-help teams fighting fires in multistory buildings are. therefore. considered to require about 3-1/2 to 4 min of search and travel time and 1 to 1-1/2 min of extinguishment time per fire on the average. Average water requirements range from negligible to about 2 gal. per fire.

The IITRI studies of Ref. 16 carry on the extinguishment investigations to include trained volunteer brigades and professional firefighters for residential-type fires beyond the capability of self-help teams. All of this information has been incorporated into Fig. 9 which relates the percentage of significant fires requiring at least the indicated action for control to the delay in starting.

Extinguishing Compartment and Building Fires

Extinguishment activity for fires beyond the flashover stage is related to the total volume or area of fire involvement according to the IITRI studies. In order to derive a relationship for manpower and resource expenditure versus extent of fire involvement, something must be known about general fire spread in compartments and buildings.

Fire Spread

To accomplish a nondetailed, stochastic treatment of fire spread, it is necessary to treat class averages. In the case of building volumes involved in fire, this includes certain assumptions concerning both the average total volume of buildings and the
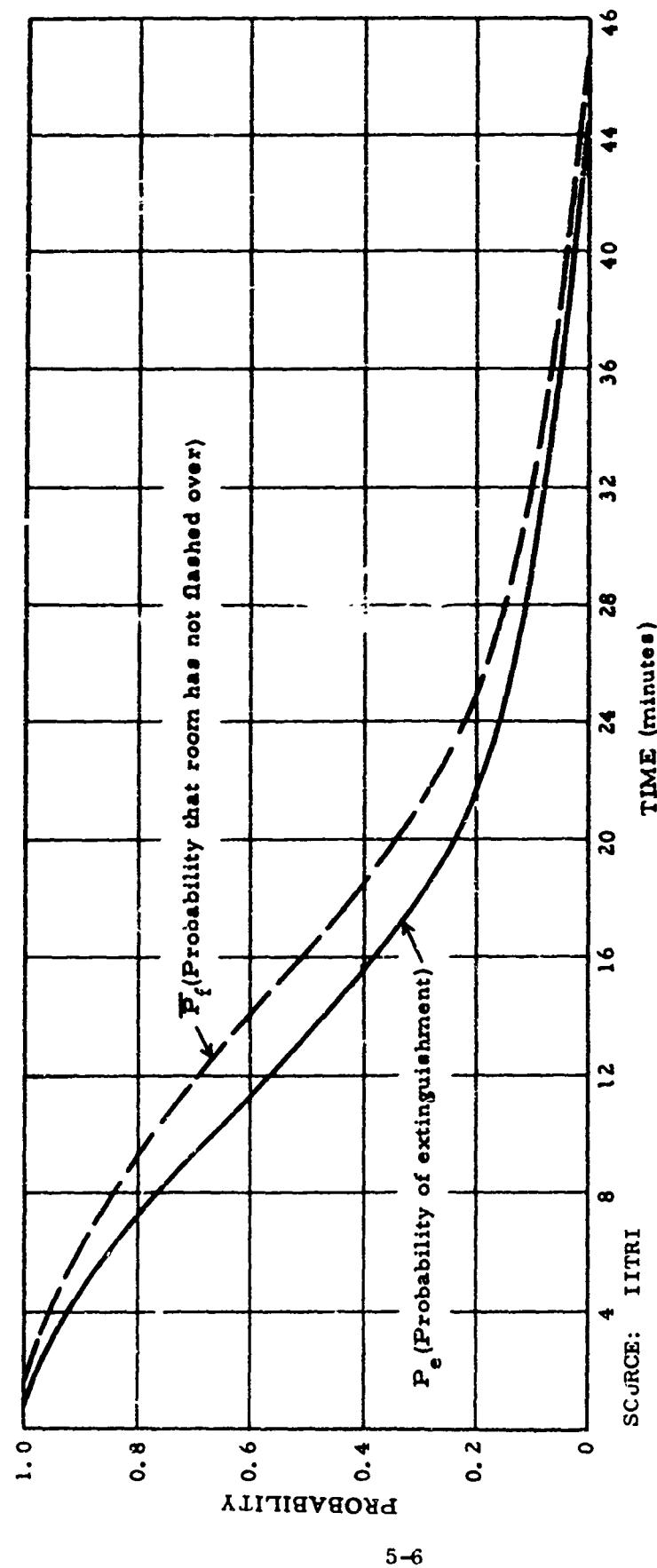
Fig. 8. Probability of Room Extinguishments by Self-Help Effort as a Function of Time

SOURCE: IITRI
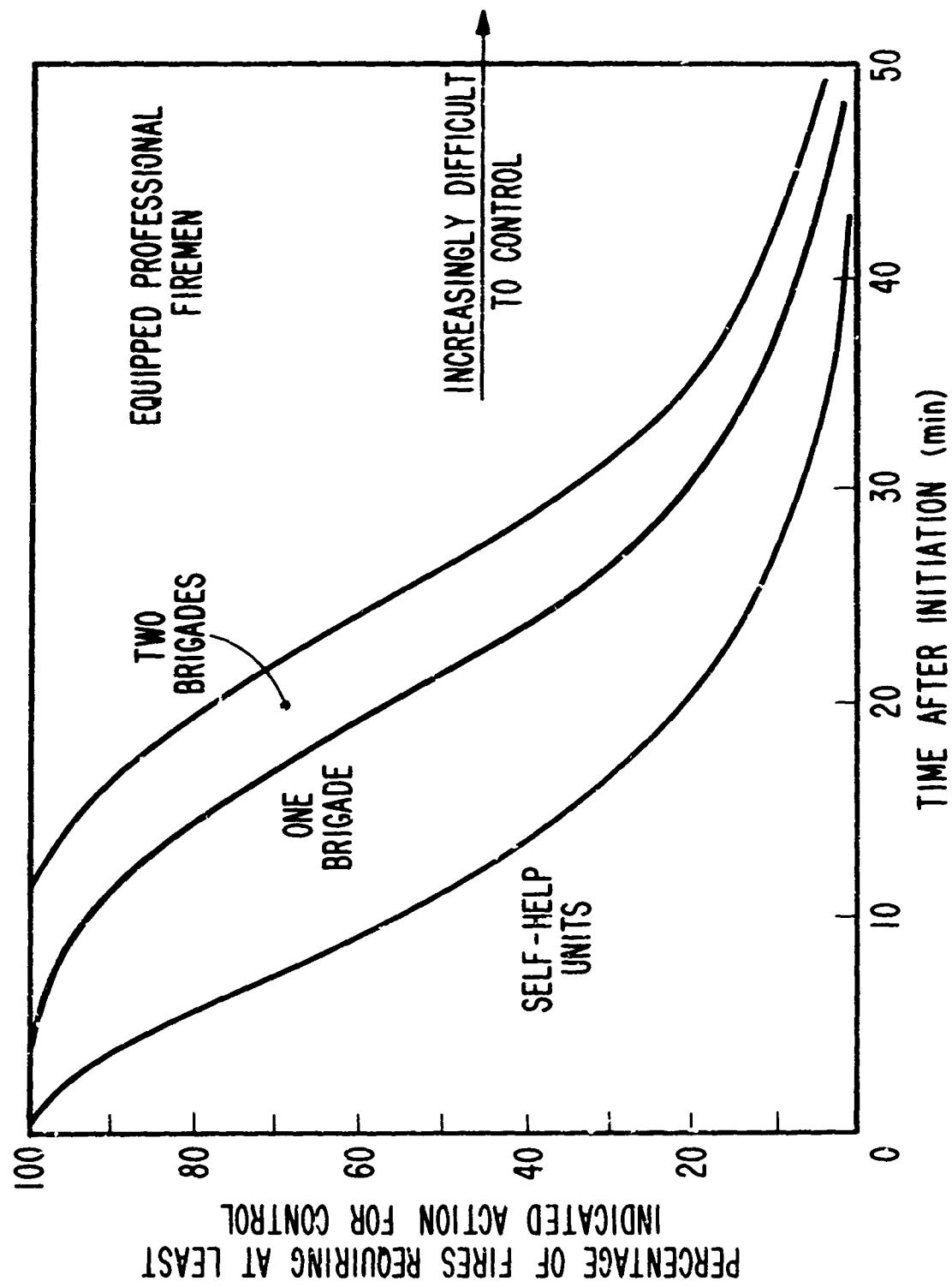
Fig. 9. Level of Effort Required to Control Initial Fires

average volume of the enclosures that make up the building for each kind (e.g., occupancy, size, types of construction) of building treated as a class. This can lead to a considerable amount of "glossing-over" of the details of fire behavior and contains the risk of providing erroneous results; however, if fire behavior is to be generalized, it is quite impractical to proceed in any more detailed fashion. There is some evidence in the limited data available from actual building burns that the cumulative volume of flashed rooms is a regular, smooth function of time after ignition at a given point in the building in spite of variations in room size (Ref. 18); so there is some justification for the following approach which treats structures as being made up of rooms of average dimension.

To express the fire spread in a building we start with the number of compartments involved or the building volume burning and describe how this quantity varies with time. For a one-story structure the process of determining the fire-spread relationship could be as follows:

1. Determine the average room area (sq ft) by dividing the total area by the number of rooms.

2. Determine the volume (cu ft) of the average room (V) and the total volume of the structure (V_T).

3. Calculate the number of rooms initially ignited by thermal radiation (or other sources) by multiplying the probability of ignition by the total number of rooms on the exposed side (or other computation depending on the ignition source).

4. Calculate the total volume of rooms initially ignited that will flash over (V_o).

5. Allow 18 min between ignition and flashover of ignited rooms.[*]

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[*]From Ref. 19, 18 min is the average time required for flashover in a room artificially ignited. It should be pointed out that experiments yielded flashover times varying from 4 min to 2 hr; however, within 10 min after ignition, only 20 percent of the test rooms had flashed and by 28 min over 80 percent had flashed. (Residential living rooms and bedrooms appear to respond differently. Although not statistically very significant, the average flashover time for bedrooms was found to be 8 min.).

6. With reference to the time of flashover of the ignited rooms, the cumulative volume (cu ft) that has undergone flashover at t minutes is

$$V(t) = V_o e^{St}, \quad V_o \leq V(t) \leq V_T. \quad \text{(Ref. 18)} \tag{1}$$

where S is the spread rate expressed in reciprocal minutes.

It follows that

$$\frac{dV(t)}{dt} = SV(t), \quad V_o \leq V(t) \leq V_T. \tag{2}$$

It may be inferred that the rate of fire spread in a single-story building (1) is proportional to the flashed-over volume, (2) depends on the volume initially ignited, and (3) is independent of the total volume of the building (until the building is burned out).

7. Estimate or determine the fuel load (lb) for the entire story.

8. Estimate or determine the total fuel load (lb) for the average room (w).

9. Estimate the fuel area (A_s) in sq ft of the average room by calculating the sum of all combustible and exposed inner surfaces of the rooms (vertical walls, floors, ceilings, etc.).

10. The burning rate (R) in lb/min for rooms during the peak fire period is

$$R = 0.09A_s \quad \text{(Ref. 19)}. \tag{3}$$

(unless fire is ventilation-controlled, in which case R = 1.5A $\sqrt{H}$, where A is area and H is height of opening in ft).

11. The duration of the peak fire period (D) in minutes in any average room is

$$D = \frac{0.5w}{0.09A_s} \quad \text{(Ref. 19)}. \tag{4}$$

12. Several characteristics of Eqs. (1) and (2) indicate that they describe only the early stages of fire development following flashover of a single room:

A. Under certain conditions buildings would contain a number of independent initial ignitions, and <u>simultaneous</u> flashover of the rooms in which they are located is very unlikely. In fact, the time to flashover of a single room is quite uncertain and has been represented as a probability distribution, as a function of time following ignition (Ref. 16). If $\mu_f(t)\,dt$ is the probability that an ignited room flashes over in the time increment t to $t + dt$ following ignition, and V_0 is the total volume of all initially ignited rooms that will flash over as a result of initial ignitions, then the average rate of volume flashover is $V_0\,\mu_f(t)$ [*].

B. Equation 2 indicates that the rate of spread is proportional to the volume that has flashed over, <u>which as time progresses includes rooms which have already burned out.</u> In an attempt to take the burning-out of rooms into account, we have designated the partial volumes which are not yet flashed over, flashed over and actively burning, and burned out, as $V_U(t)$, $V_F(t)$ and $V_B(t)$ respectively, and have retained the exponential functionality while making the more reasonable assumption that

$$\frac{\partial V_F(t)}{\partial t} \propto S V_F(t).$$

Since the total volume of the building must be equal to the partial volumes, i.e.,

$$V_T = V_U(t) + V_F(t) + V_B(t), \tag{5}$$

the volume flashed over and actively burning at any time is also determined by $V_U(t)$ and $V_B(t)$. These relationships can be expressed as

---

[*]The integral $P_f(t) = \int_0^t \mu_f(t)\,dt$ is the probability that a randomly selected room has flashed over by time t. This quantity is reported in Ref. 16.

$$\frac{\partial V_F(t)}{\partial t} = V_o \mu_f(t) + SV_F(t) - \frac{\partial V_B(t)}{\partial t}$$

Taking partial derivatives of Eq. (5)

$$\frac{\partial V_U(t)}{\partial t} = - \frac{\partial V_F(t)}{\partial t} - \frac{\partial V_B(t)}{\partial t}$$

and substituting the expression for $\dfrac{\partial V_F(t)}{\partial t}$ yields

$$\frac{\partial V_U(t)}{\partial t} = - V_o \mu_f(t) - SV_F(t) \tag{6}$$

C. The period of active burning of a structure exceeds the burn
    duration of individual rooms, and therefore the entire volume
    of a building does not burn out simultaneously. Assuming that
    all ignited volume elements burn for the same length of time,
    D (the peak fire period of an average room), then each volume
    element which was ignited a time D earlier will burn out at
    time t, or

$$\frac{\partial V_B(t)}{\partial t} = - \frac{\partial V_U(t-D)}{\partial t} = S V_F(t-D) + V_o \mu_f(t-D) \tag{7}$$

For multistory structures, the additional considerations for vertical
spread must be incorporated. The following basic data inputs from IITRI
studies (Ref. 19) will apply for vertical spread conditions:

● Room flashover to ceiling penetration (if combustible): 25 min

● Flashover of stairwell on one story to flashover of stairwells on
  all upper stories: 10 min

● Flashover of stairwell on one story to flashover of stairwell in
  next lower story: 30 min

Extinguishment Rate Considerations

One method of treating the problem of controlling compartment and building fires is to introduce and develop the extinguishment rate concept. We may define the fire volume at any time relative to its initial value as

$$F(t) \equiv \frac{V(t)}{V_o}$$

According to Eq. (1), if the fire burns without attempted control

$$F = e^{St}$$

and, therefore, $dF/dt = Se^{St} = SF$. If, however, extinguishment is applied after a time t_1 at a rate E (volume extinguished per unit time), the time rate of change of F can readily be seen to be

$$\frac{dF(t)}{dt} = \begin{cases} SF(t), & 0 \le t < t_1 \\ \\ SF(t) - E/V_o, & t_1 \le t \le t_x \end{cases} \qquad (8)$$

where t_x is the time at which extinguishment is complete. [*]

Letting the value of F at the time extinguishment action begins be

$$F_1 = e^{St_1}$$

_____

[*] It should be pointed out that the quantity t_x in Eq. (8) is to be interpreted physically as being the time at which the active flaming combustion of a structure is suppressed rather than the time of complete extinguishment. That is to say, it does not include the relatively long time required to overhaul a fire by extinguishing all of the relatively minor residual combustion. Therefore, the interval $t_x - t_1$ can be regarded as being the time taken to gain control of the active fire once extinguishment activity begins, which we can express as t_c. A fire which has been controlled in this manner may not be left unattended for very long without accomplishing complete extinguishment, since there is the possibility that the residual combustion would result in reinvolvement of the structure.

and integrating the function $F(t)$ over the period of extinguishment. viz.

$$\int_{F = F_1}^{F = 0} \frac{d\left(F - E/SV_o\right)}{F - E/SV_o} = \int_{t = t_1}^{t = t_x} S dt.$$

the following expression for extinguishment time results:

$$t_x = 1/S \, \ell n \left(\frac{E/SV_o}{E/SV_o - F_1}\right) - t_1 \qquad (9)$$

From this equation we can conclude that a given fire is extinguishable for the condition satisfied by

$$E/SV_o > F_1$$

or whenever

$$t_1 < 1/S \, \ell n \, (E/SV_o) \qquad (10)$$

The foregoing equations allow the interrelationships of extinguishment rate, extinguishment time, and the delay in applying control to be examined. These are displayed in Fig. 10.

To be truly useful, the extinguishment rate should be expressed in terms of the application rate of water. It is reasonable to expect that one is proportional to the other. We have taken this as a working hypothesis expressed as

$$Q = cE \qquad (11)$$

where Q is the volume application rate of water (gpm) and the constant of proportionality c has the units of gallons (of water applied) per cubic foot (of flashed over volume suppressed). We are unable to find information suitable

E/V_o = EXTINGUISHMENT RATE (minutes^{-1})

$= \dfrac{\text{VOLUME EXTINGUISHED PER UNIT TIME}}{\text{VOLUME OF ROOMS INITIALLY IGNITED}}$
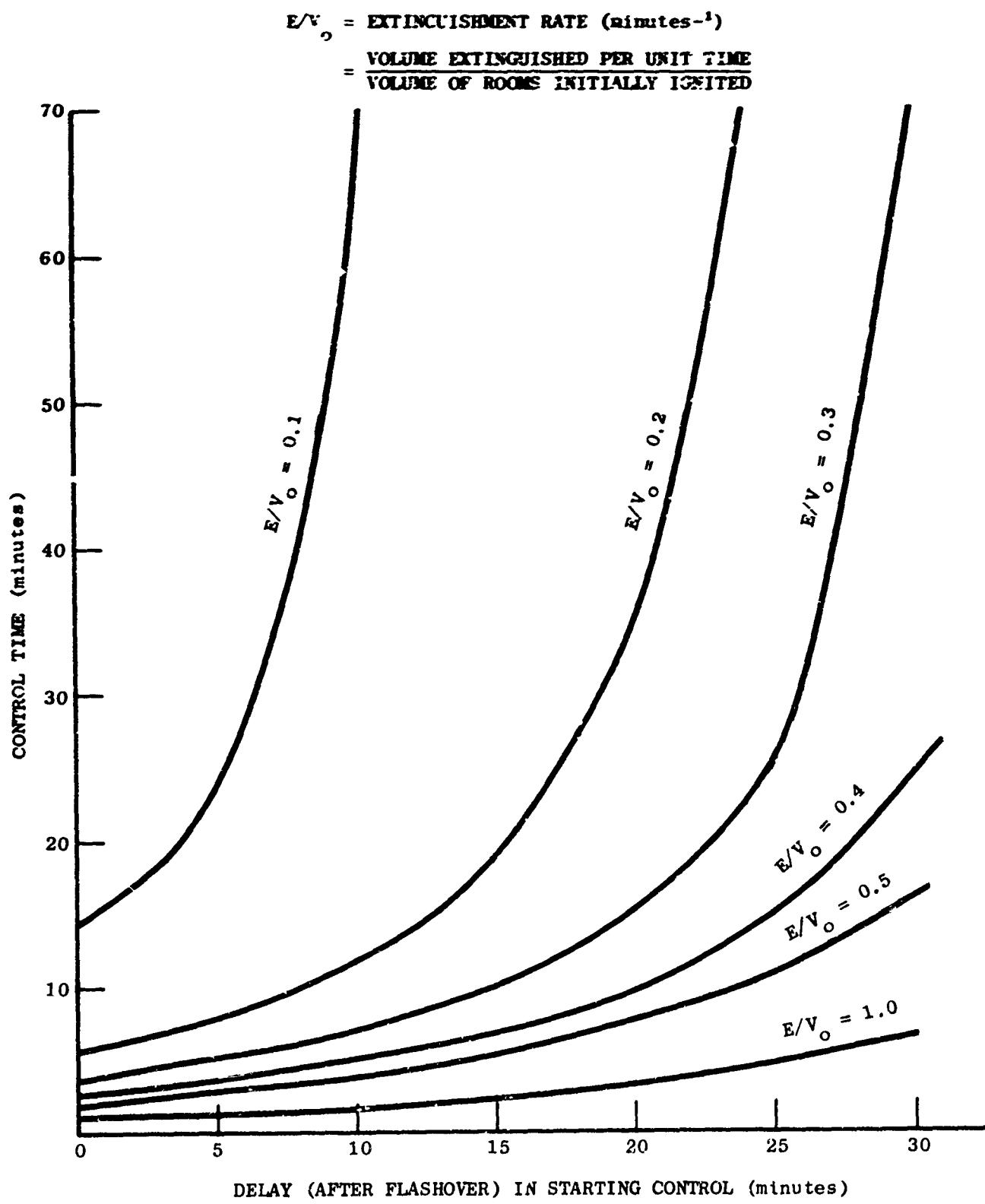
Fig. 10. Time to Control Fire as a Function of Delay Following Flashover Before Control is Started for Various Extinguishment Rates

5-14

to the direct evaluation of c; however, we have accomplished an evaluation which is generally consistent with fire experience. using the equations developed above. This evaluation is described in the following paragraphs.

Empirical data on times required to control residential and nonresidential fires (t_c) and on the corresponding application rates of water (Q) are related to the total fire area (A_2) in a recent IITRI report (Ref. 20). From these data a relationship between the volume rate of water application and the corresponding volume rate of extinguishment can be derived if the changes in fire-involved area during control activity, as well as its growth before control activity starts, are accounted for in the analysis. These quantities are not given explicitly among the data of the referenced report; however, they can be deduced by applying the equations developed here as a data correlating device.

As indicated earlier, the control time, t_c , is expressed by the interval $t_x - t_1$, and can be regarded as being the time taken to gain control of the active fire once extinguishment actively begins. From Eq. (9) we can express the control time as

$$t_c = t_x - t_1 = 1/S \, \ell n \left(\frac{E/SV_o}{E/SV_o - F_1} \right)$$

or

$$t_c = - 1/S \, \ell n \left(1 - \frac{SV_o}{E} F_1 \right)$$

Recalling that $V_o = V_1 e^{-St_1}$, and $F_1 = e^{St_1}$, and making the appropriate substitutions, the equation for control time becomes

$$t_c = - 1/S \, \ell n \left(1 - \frac{SV_1}{E} \right) \tag{12}$$

At this point it is necessary to make the further assumption that the volume (V_1) of fire involvement at the time successful control activity begins is the largest value attained during the course of the fire[*] and that it is equivalent to the IITRI fire area, A_2, i.e.,

$$V_1 = hA_2 \tag{13}$$

in which h is the average ceiling height. Substituting Eqs. (11) and (13) into Eq. (12) we obtain

$$t_c = -1/S \ \ln\left(1 - \frac{chSA_2}{Q}\right) \tag{14}$$

or the alternative form

$$A_2/Q = \frac{1}{ch_{-}}\left(1 - e^{-St_c}\right) \tag{15}$$

To test the capability of this function to correlate the IITRI operational data, A_2/Q and $1 - e^{-St_c}$ were calculated[**] from the values reported in Ref. 20, and a least squares fit to the line

$$Y = A + BX$$

where

$$Y = A_2/Q \text{ and } X = 1 - e^{-St_c}$$

was obtained. Because of physical arguments, the Y-intercept is expected to be at the origin, if the data correlate on this basis. It was not necessary to impose this constraint, however. since the Y-intercept of the least squares fit (the expected value of A) turns out to be not significantly different from zero as indicated by the 95-percent confidence interval. Inserting the expected value of B in the relation

$$B = \frac{1}{chS} = \frac{1.8}{c}$$

---

[*]For the mathematical model we are using, this is always the case if control is attained.

[**]Assuming ceiling heights to average 10 ft and the spread rate constant $S = 1/18 \text{ min}^{-1}$. See Ref. 18 for justification.

the expected value of c was calculated to be 0.4 ± 0.2 gal/cu ft. The resultant uncertainty is large, but variance in the data is also large. In fact, a simple analysis was made without taking into account the growth of fire during extinguishment, and some of the resulting values of c differed by more than an order of magnitude. Correlation of the data by the more refined analysis is probably about as good as might reasonably be expected considering the nature of the data, which incidentally is adequately represented by Eq. (15).

Attempts at correlating the operational data (Ref. 20) using simple linear relationships fail because the exponential growth of fire during operations is ignored (presumably the rate of growth is less than the rate of extinguishment). If the control period, t_c, is short ($t_c << \frac{1}{S}$), the water usage Q/V_1 is proportional to $1/t_c$, and, as expected

$$Qt_c \propto V_1 \propto A_2$$

However, for long control periods ($t_c >> \frac{1}{S}$), $Q \propto V_1 \propto A_2$ (Q/A_2 approaches a constant value).

Using the results given above, Eq. (9) can be rewritten as

$$t_c = -1/S \ln\left(1 - \frac{cSV_o}{Q} e^{St_1}\right) . \tag{16}$$

To illustrate the use of extinguishment under this concept, a concrete example is useful. Without extinguishment, the spread of fire through a building can be numerically evaluated by means of Eqs. (5), (6), and (7).[*] By assuming conditions of initially expected flashover volumes, peak burn duration of an average room (say 30 min), and spread rate, we can calculate the fire history in buildings. Figures 11 and 12 illustrate two examples of this for initially flashed over volumes of 10 and 50 percent. In these examples we can now apply

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[*] A computer program was written to facilitate numerical evaluation of these expressions.
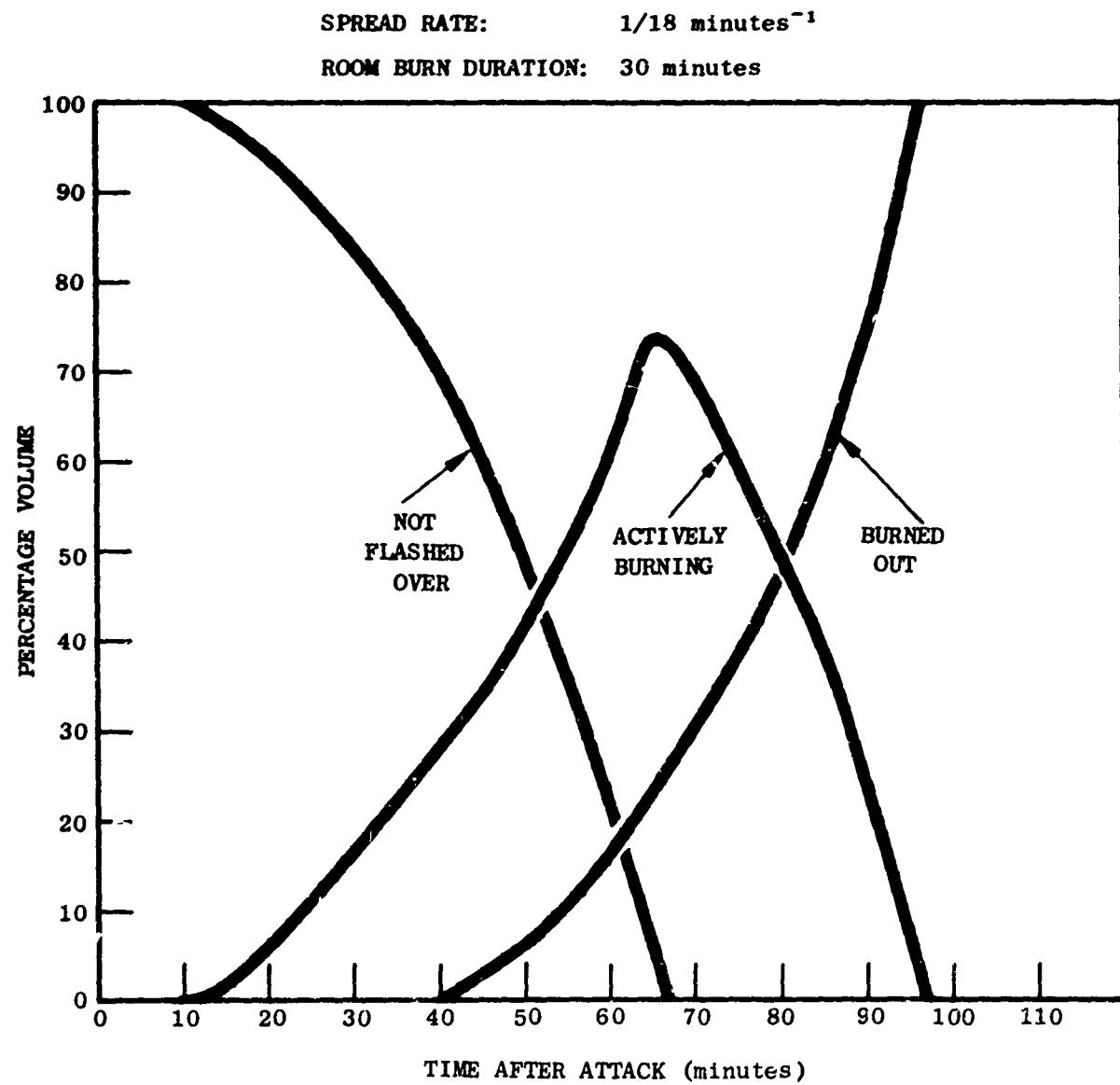
SPREAD RATE: $1/18$ minutes^{-1}

ROOM BURN DURATION: 30 minutes

Fig. 11. Fire Buildup and Decay in a Structure when 10 Percent of the Rooms
          are Initially Ignited

SPREAD RATE: $1/18$ minutes^{-1}

ROOM BURN DURATION: 30 minutes
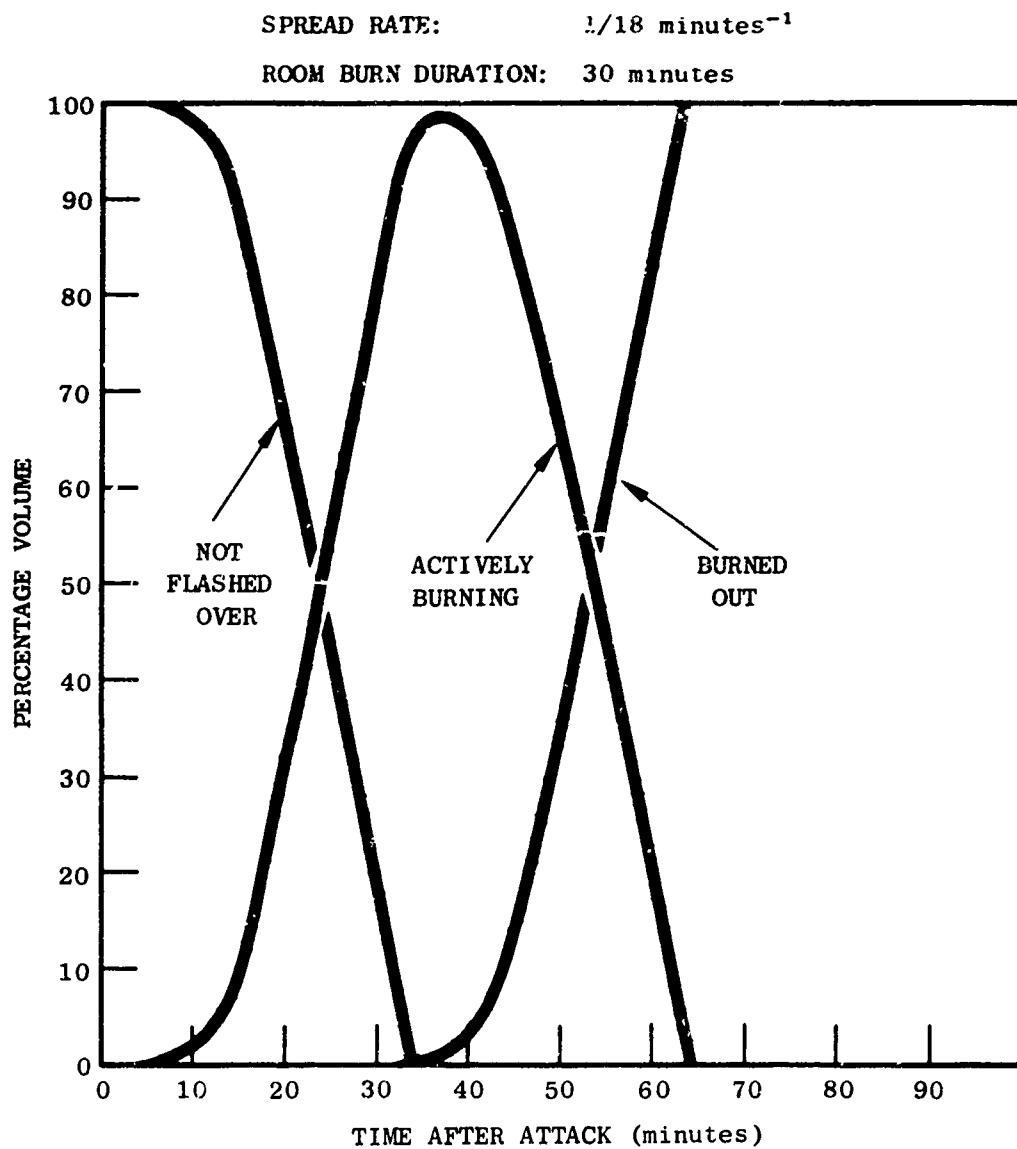
Fig. 12. Fire Buildup and Decay in a Structure when 50 Percent of the Rooms are Initially Ignited

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extinguishment after a given delay and estimate the change in fire history as a result. Figure 13 shows the result of one such calculation for an initially ignited volume of 10 percent, an extinguishment rate (E/V_0) of 0.01 min^{-1}, and a delay in attempting control of 40 min. In this case control is not achieved because of the combination of low extinguishment rate and long delay in initiating control. The numerical method used in calculating the curve of Fig. 13 is not yet reliably programmed for computer solution, and the following example employs the simpler analytical method described earlier.

Another example — one in which control is achieved — is the case of a 50,000-cu-ft building in which 10 percent (5000 cu ft) is initially flashed over and water at a rate of 800 gpm (typical capacity of a modern pumper) is applied starting 25 min after flashover occurs (about 40 min after initiation). For this case E would be approximately 2000 cu ft min^{-1} (E = Q/c = 800/0.4). According to Eq. (1), by the time control activity begins the flashed-over volume will have grown to 20.000 cu ft (corresponding to a floor area of 2000 sq ft in a building with 10-ft ceilings), and according to Fig. 10 (for E/V_0 = 2000/5000 and t_1 = 25 min), 14 min would be required to knock the fire down to the point where the 800-gpm pumper could be replaced by self-help forces and move on to another fire. For the same building and the same delay, control would not be achieved if 400 gpm or less were applied [according to Eq. (10)]; whereas control could be achieved in less than 20 min at the reduced rate of application if control activity began within 15 min after flashover.

These methods of evaluating extinguishment capability are conducive to computer calculation and as such can be applied readily to a formal model of fire service performance.

Controlling Building-to-Building Fire Spread

The spread of fire from one building to another may take place by a number of mechanisms. Where there is no separation between buildings, spread may occur
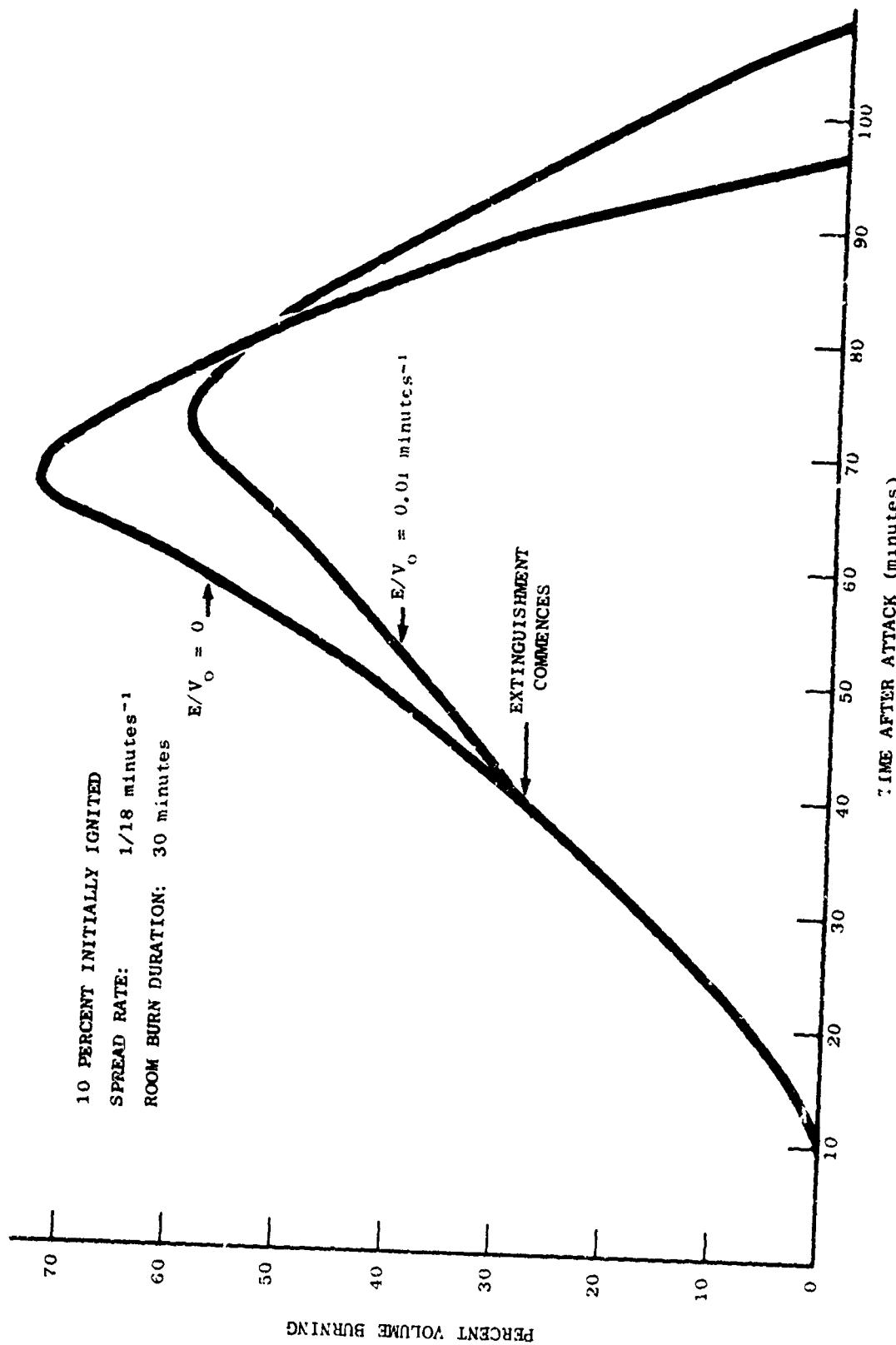
Fig. 13. Fire Buildup and Decay in a Structure when 10 Percent of the Rooms are Initially Ignited and Inadequate Extinguishment is First Applied 40 min After Attack

by a penetration process, which is merely an extension of spread from compartment to a compartment within one building. Where buildings are physically separated, spread may proceed by convection, radiation, or firebrands. The problem of spread by radiation has been studied sufficiently to permit the calculation of certain performance relationships. Factors related to spread by radiation and two methods of controlling spread will be given in the following paragraphs.

Fire Intensity

As a measure of fire intensity one could use the burning rate or heat release rate. Equation (3) already gives us the burning rate during peak fire for a well ventilated fire, viz., $R = 0.09A_s$. A determination of the volume of the structure burning at any time, $V_F(t)$, can be obtained by use of Eq. (7). This relationship along with the average room volume can then be used to yield the burning rate at any time, viz.,

$$R(t) = \frac{V_F(t)}{v} \times 0.09\,A_s \qquad (17)$$

This equation would be in units of lb/min and could be converted to Btu/min by multiplying by 8,000 Btu/lb (the average heating value for wood) or any other suitable value to reflect the specific occupancy or building class or construction material used.

Exposure Control

The basic problem of exposure control is to prevent ignition of a non-burning structure as it is being exposed to the thermal radiation, heating by convection currents, and firebrands arising from a nearby, but separated, burning structure. In most circumstances the important fire-spread, heat-transfer mechanism for spread between closely spaced buildings is thermal radiation, and this section deals solely with handling the

problem of reducing the incident thermal radiation to below ignition levels.

Two specific methods of exposure control are examined in this report. The first method is the simple erection of a water screen at some plane in between the exposed and the burning structures. The other method involves actually spraying the exposed surfaces with streams of water.

Water Screens

The thermal energy at the radiating surface (I_o) can be taken as 4 cal/ cm^2-sec (Ref. 21) since most buildings will have fuel loads greater than 5 lb/sq ft. The exposed surface will be protected if the incident radiation is reduced below 0.8 cal/cm^2-sec.[*] To determine the radiation level at the exposed surface, the following procedure is performed:

1. Estimate the distance (C) between the burning and exposed buildings.

2. Estimate the smaller dimension (A) — horizontal or vertical — of the radiating face (the entire face of the burning building).

3. Estimate the ratio (R) of the larger to smaller dimension of the radiating face.

4. Estimate the fraction (W) of radiating face occupied by any combustible surface and window area. If the entire face of the building is combustible, then W = 1 and if no portion of the face is combustible, then W is equal to the fraction of window area.

5. Calculate the parameter RA/C.

6. From the graph of Fig. 14, read off the value of the configuration factor (φ)[**], using the appropriate R.

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[*]Reference 21 also indicates that the incident radiation would have to be reduced below 0.3 cal/cm^2-sec for pilot ignition. Recent data (Ref. 22) indicates that spontaneous ignition may occur for radiation values as low as 0.4 cal/cm^2-sec.

[**]Note that φ is 1/4 the configuration factor $\bar{\varphi}$.
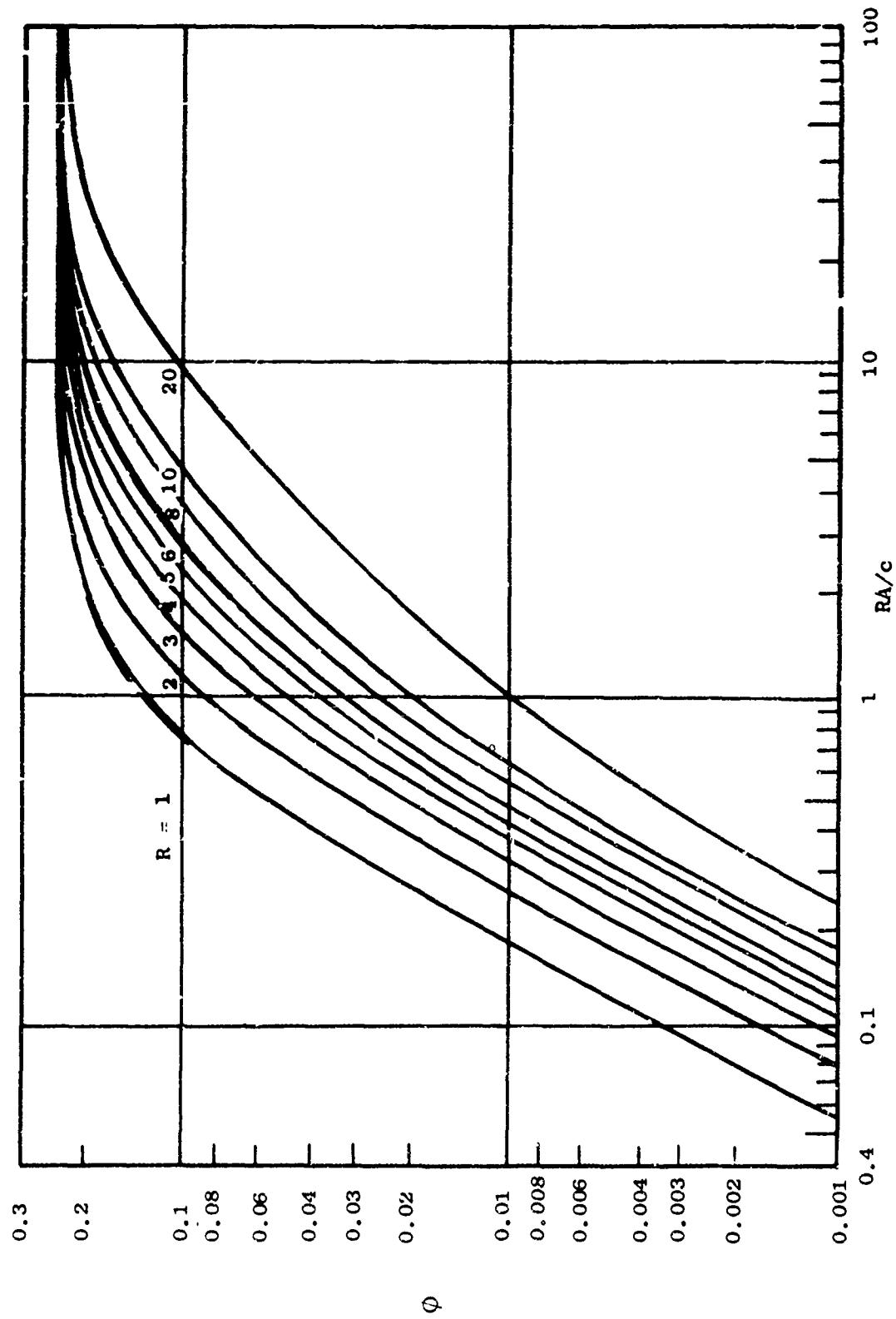
Fig. 14. Configuration Factor φ for Differently Shaped Radiators

7. Calculate the unreduced radiation (I_u) at the exposed surface from the formula:

$$\phi = 4\varphi = \frac{I_u}{4W} \quad \text{or} \quad I_u = 16W\varphi \quad \text{(Ref. 21).} \tag{18}$$

If I_u is less than 0.8 cal/cm^2-sec then no action is needed, but if it exceeds that value, the excess must be removed by the water screen.

The water screen thus will have a required maximum transmission (T) of:

$$T = \frac{0.8}{I_u} \tag{19}$$

The screen actually consists of tiny water droplets with an assumed typical radius of 100μ .* A calculation of the energy removed by these droplets is required. The extinction (absorption plus scattering) cross section A(r) or effective area of a single droplet is:

$$A(r) = \pi r^2 Ke \tag{20}$$

where r is the droplet radius and Ke is the extinction coefficient.

Extinction cross section as a function of wavelength is given for various radii of water droplets by Arnulf et al. (Ref. 24).

For radiation normally incident on a plane cloud of droplets, the following transmission equation applies:

$$T = e^{-NA(r)L} \quad \text{or} \quad NA(r)L = -\ell n\, T$$

where N is the number of droplets per cm^3 and L is the screen thickness in cm. This expression may be changed to include the relationship for transmission from Eqs. (18) and (19), viz.,

---

*Typical pressure nozzles produce droplets with radii varying from 5 to 250μ , with only about 1 percent of the droplets in excess of 100μ (Ref. 23).

$$NA(r)L = -\ell n \left(\frac{0.8}{16W\phi}\right) \tag{22}$$

For a screen with a base of b cm and a vertical velocity of U cm/sec, the water flow rate (R) in cm^3/sec required to sustain the screen is

$$R = (NLbU) \left(\frac{4}{3}\pi r^3\right) \tag{23}$$

For the droplet size range indicated, Stokes law applies, and the terminal settling velocity of the particles is expressed by

$$U = \left(\frac{2\rho g r^2}{9\eta}\right) \tag{24}$$

where ρ is the droplet density in gm/cm^3, g is the acceleration due to gravity in cm/sec^2, and η is the air viscosity in poise.

The water flow-rate equation may now be expressed in more fundamental terms by substitution of the equivalent for U from Eq. (24) in Eq. (23), viz.,

$$R = (NLb) \left(\frac{2\rho g r^2}{9\eta}\right)\left(\frac{4}{3}\pi r^3\right) \tag{25}$$

By use of the expression for N from Eq. (22), we now have

$$R = \left(-\frac{1}{A(r)L}\ell n\frac{0.8}{16W\phi}\right)(Lb)\left(\frac{2\rho g r^2}{9\eta}\right)\left(\frac{4}{3}\pi r^3\right)$$

$$R = \left(\frac{8\pi}{27\eta}\right)\left(\frac{\rho g r^5}{A(r)}\right)b\,\ell n\,\frac{W\phi}{0.05} \tag{26}$$

Under the assumptions used in this analysis, this expression gives the water flow rate required to maintain a water screen with base b which will reduce the incident thermal energy below ignition level.

Spraying the Exposed Surface

For this method of exposure control, the unreduced radiation at the exposed surface is first absorbed by the outer layer of the surface and then removed conductively by the water layer sprayed on. The maximum energy removed by the water layer would be the sum of the energy required to raise the water temperature from say 25 to $100°C$ plus the heat of vaporization. This sum is 613.7 cal/cm^3.

If the water layer is applied at the rate θ cm/sec, then we have a minimum requirement for protection

$$I_u - 0.8 = 613.7\theta \qquad (27)$$

or

$$\theta = \frac{I_u - 0.8}{613.7}$$

Substituting Eq. (18) for I_u and converting to ft/sec yields

$$\theta = 4.28 \times 10^{-4} (2W\phi - 0.1). \qquad (28)$$

If the total surface area to be sprayed is A sq ft, then the rate of water usage required (R gal/hr) is

$$R = 11.5A(2W\phi - 0.1). \qquad (29)$$

Damage to Fire Vehicles

It is important to be able to estimate damage to the mobile equipment and the length of time needed for repair of vehicles in various damage categories. The degree of damage to fire trucks and rescue vehicles depends both on the shelter available and on the conditions of blast and thermal radiation characteristics of the nuclear weapon. If the vehicles are parked indoors in closed garages, their damage

will be primarily determined by the vulnerability of the structure. This discussion
will be limited to vehicles parked outside.

The blast damage to vehicles is an increasing function of both the peak
overpressure and the duration of the pulse. As the weapon size is increased, the
duration of the shock front is lengthened. Thus, the damage caused by large weapons
is greater than that caused by smaller weapons at points of equal peak overpressure.
Figure 15 gives the relation between peak overpressure and weapon size for light,
moderate, and severe damage to vehicles. This figure was constructed from data
given in Refs. 6, 25, and 26.

Severe damage is defined as gross distortion of the frame with the possibility
of complete dismemberment. Moderate damage is given as wheels and undercarriage
damaged or dismembered, and/or engine damaged, with overturning probable.
Examples of light damage are glass breakage, some bending of fenders, and denting
of hoods. It may be noted that the peak overpressure at which light damage occurs
is nearly independent of weapon size. Glass breakage and similar damage does not
require a force acting over a long period and thus depends almost entirely on the
peak overpressure. It should also be noted that all forms of damage are weakly yield
dependent for megaton yields.

Vehicles undergoing severe damage may be considered to be useless for
firefighting purposes in the postattack period except for the possibility of providing
spare parts for repairing less severely damaged vehicles. Many moderately damaged
vehicles should be capable of being used after 1 or 2 hours of repair; however, special
equipment or personnel might be required. Lightly damaged vehicles could be made
operational by the operator within about a half hour. The severity of damage of a
vehicle depends to a certain extent on its orientation with respect to the blast wave.
Those vehicles facing forward or away from the blast are more resistant to
overturning and are thus less likely to be heavily damaged.
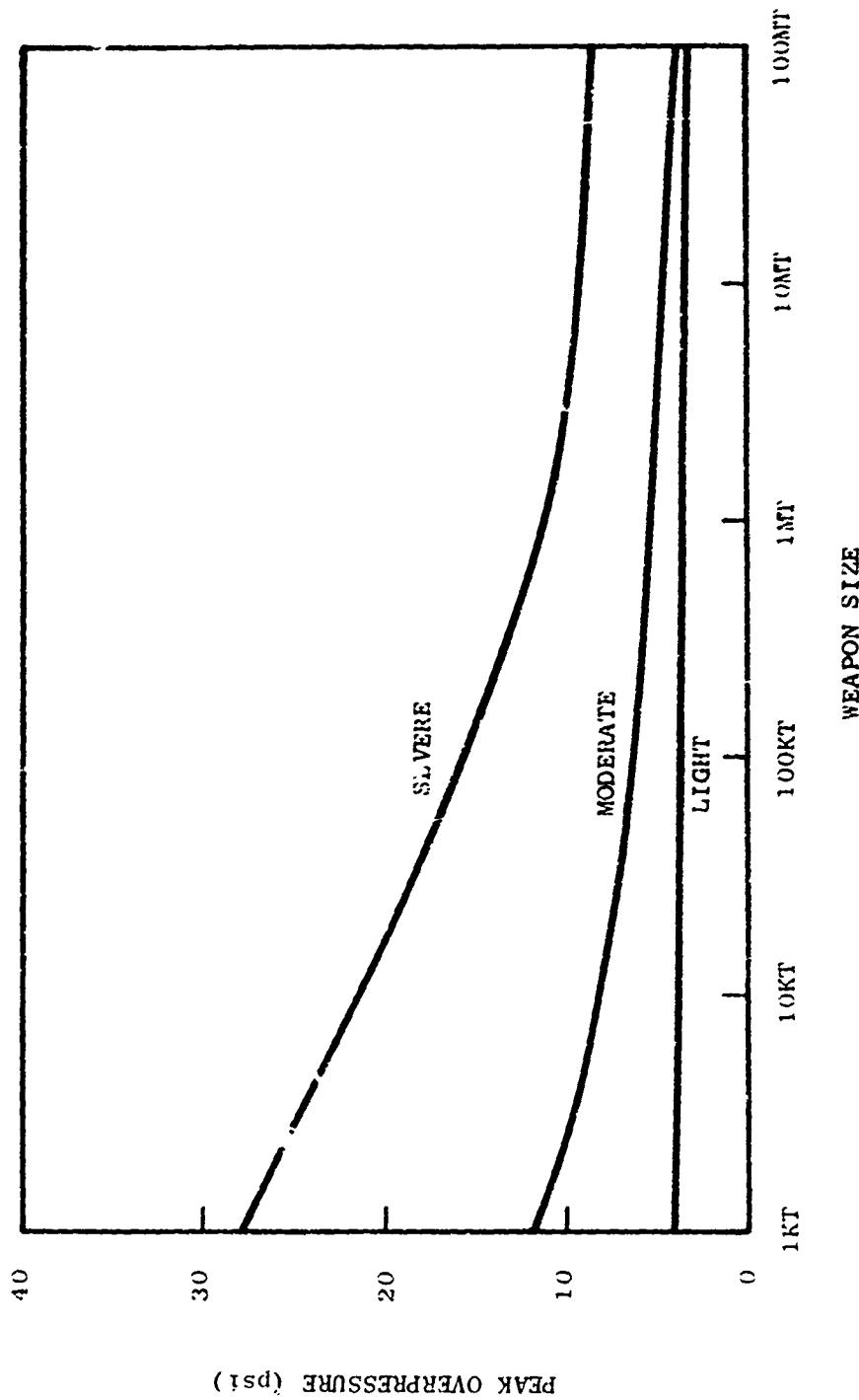
Fig. 15. Vehicle Damage Levels for Various Weapon Conditions

RESCUE ACTIVITIES

The overall objective of rescue is, of course, to save lives. The tasks to be performed include:

1. Search for survivors who are at risk

2. Release of trapped survivors

3. Administration of first-aid to injured survivors at site of rescue

4. Movement of survivors to safe quarters

A detailed "urban area" description is necessary in defining the magnitude of the rescue problem because the number and types of injuries sustained by survivors of a nuclear attack, as well as the number who are trapped, are strongly dependent on the types of construction in the urban area. The nature of the urban area also affects debris levels and, therefore, the time required to search for survivors and to transport them to safe quarters.

The main problem in establishing rescue effort requirements becomes a matter of determining the degree of risk to and condition of the survivors. Functional relationships valid for the wide variety of postattack conditions depend on the availability of the following types of data.

1. Casualty and trapping functions providing number, condition, and location of survivors. Useful data are presented in Refs. 10, 11, and 27, and it is expected that the necessary relations could be extracted from these sources.

2. Debris levels can be predicted by the methods presented in Ref. 8. Speed of movement over debris is estimated in Ref. 28. An analysis of search time (man-hours per unit area) is presented earlier in the present report. These sources should provide enough information to estimate effort requirements for search and transport of survivors to safe quarters.

3. Effort required to release each trapped survivor is expected to decrease with increasing survivor density since casualties would be grouped together in the safest areas available. Some data are presented in Ref. 10 and additional data may be obtained from reports of natural disasters.

4. Effort required to administer first-aid to the various casualties. It has been suggested[*] that the following emergency treatments be given priority in the order listed: (1) stop bleeding by application of pressure bandages. (2) treat for shock, and (3) splint severe fractures. Reports of emergency medical treatment under combat conditions may provide useful information.

5. Prognosis for recovery from various types of injuries as a function of the waiting period preceding rescue.

6. Prognosis for recovery after exposure to fallout radiation. Exposure dosage can be estimated using procedures given in Refs. 29, 30, 31, and 6. Mortality data are given in Ref. 32.

7. The number and distribution of burn victims and their chances for recovery are not readily ascertained. It can be assumed that the arrival of the fire front probably results in instantaneous death for some fraction of the trapped and non-ambulatory survivors.

Need for Relocating Survivors

Survivors in the postattack period may require relocation due to (1) the uncontrollable nature of the fire situation, (2) the need to seek better shelter from fallout effects (blast damage in the absence of a fire problem), or (3) because of the need for medical attention to injured personnel. The most common reason for relocation will no doubt be uncontrollable fires, which could be due to initial ignitions in the area or a result of fire spread from other areas.

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*D. B. Wallace, oral communication.

Casualty/Injury Relationships

Based on the experience in Japanese cities subjected to nuclear weapon attack, several investigators (Refs. 10 and 11) have presented casualty curves for various building types. The casualties are categorized in a number of ways. We have attempted to group casualties in a way that will facilitate rescue requirement calculations. The casualty curves developed here (Figs. 16 through 21) are based on a 10-Mt surface burst. These represent the condition of survivors in six different types of buildings at the end of the first day after attack, grouped as follows:

1. Uninjured (UI) - Survivors receiving no injuries or only minor injuries requiring no medical treatment for continued survival.

2. Lightly Injured (LI) - Survivors suffering injuries that require only minimal medical care for continued survival.

3. Ambulatory Seriously Injured (ASI) - Survivors who, although ambulatory initially, have suffered injuries which will result in death within the next 60 days unless they receive more than minimal medical care.

4. Nonambulatory Seriously Injured (NSI) - Survivors who are injured so severely that they cannot move themselves and will die within 60 days unless they receive more than minimal medical care.

5. Trapped (T) - Survivors confined by blast-caused debris so that they cannot escape without help. Although this category is separate from the categories above, included persons will be in the UI to NSI states in unspecified proportions.

The six building types used are defined in Refs. 10 and 11 as follows:

1. **Wood-Frame Buildings.** This category consists of relatively light wood frame homes and home-industry of pre-war Japan.

2. **Load-Bearing Brick Wall Buildings (BR).** Buildings in this category are comparable to nonreinforced U.S. load-bearing brick construction.

URS 673-3
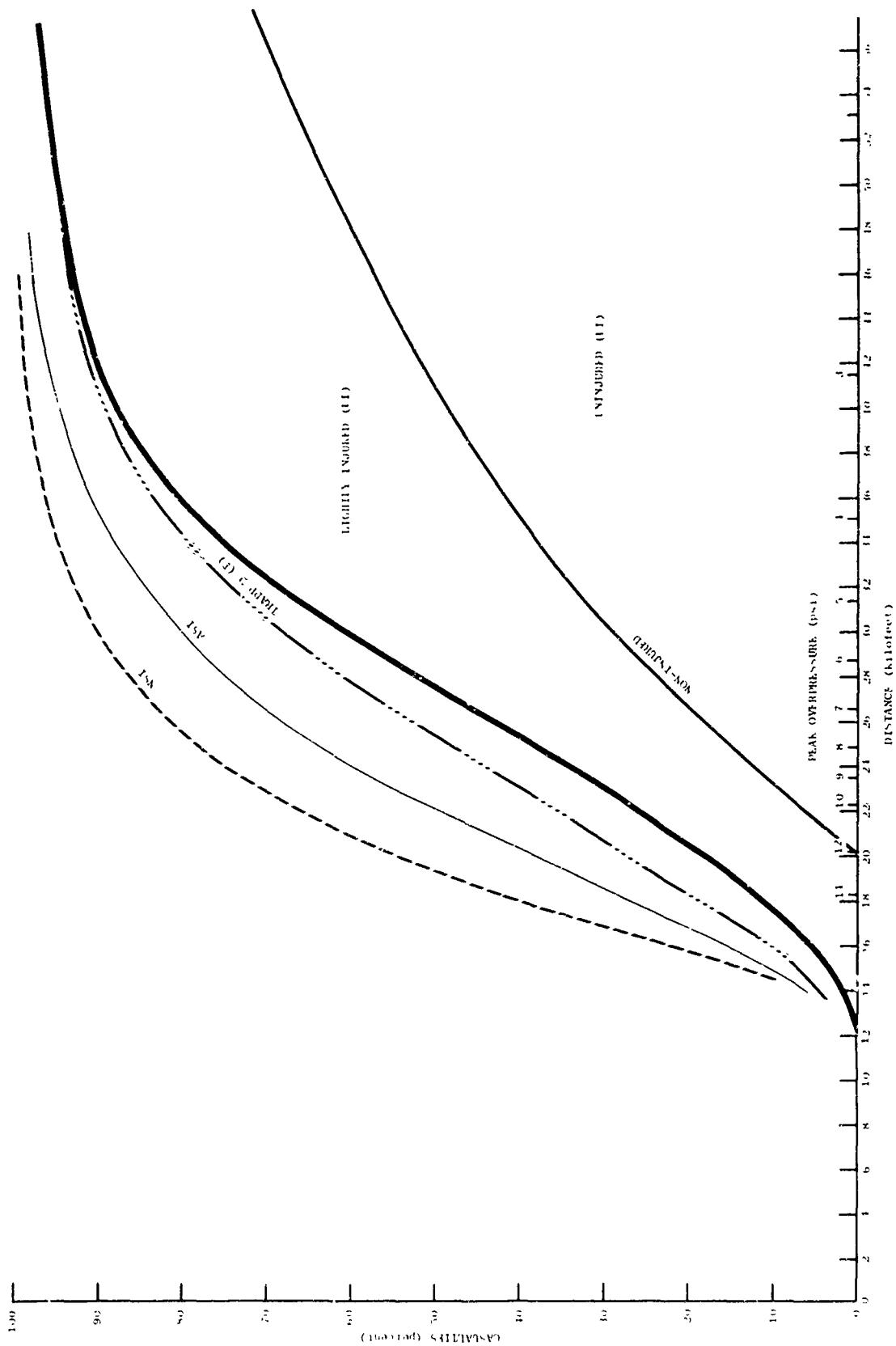
Fig. 16. Percent Casualties vs Distance for 10-Mt Surface Burst
(wood frame construction)
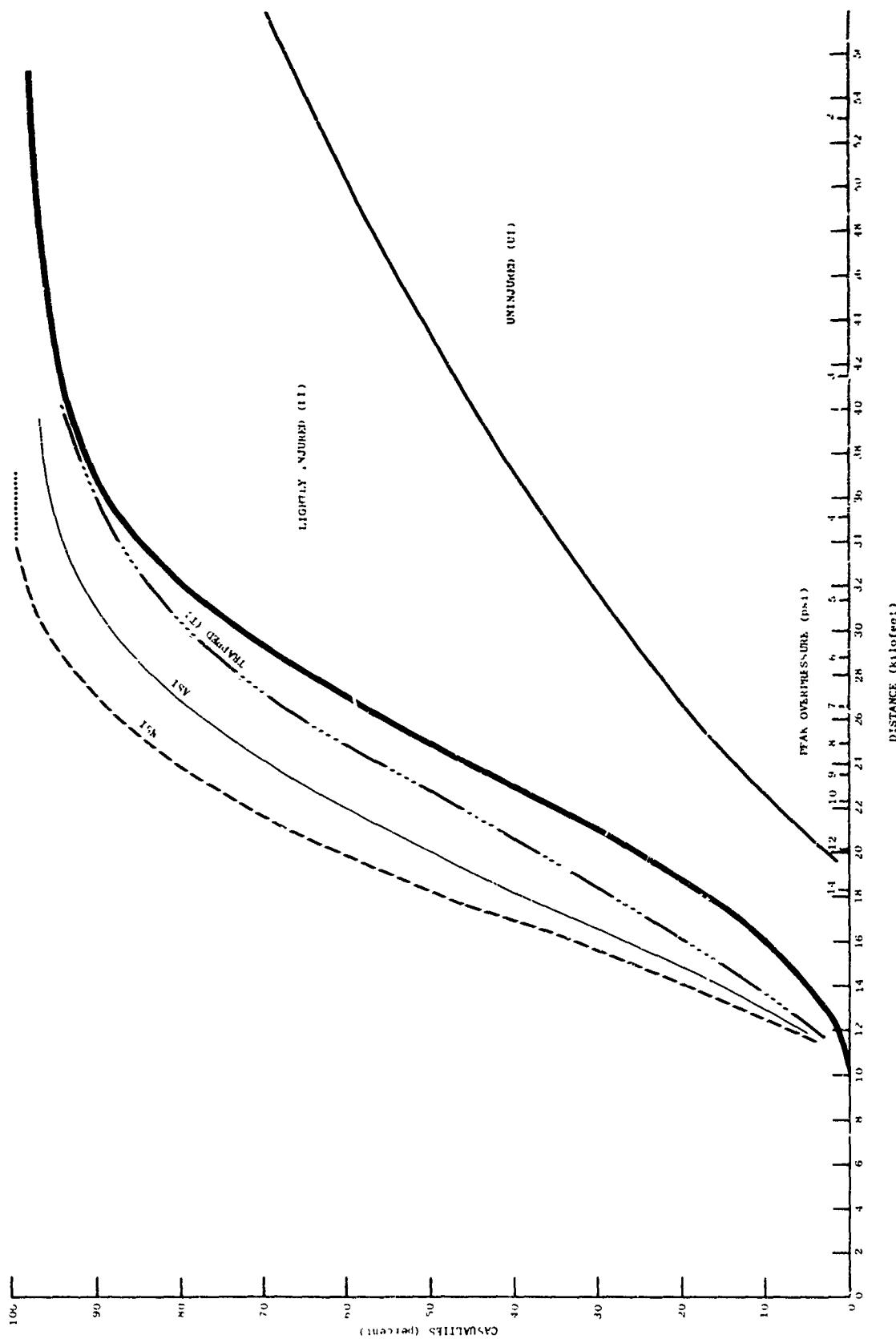
Fig. 17. Percent Casualties vs Distance for 10-Mt Surface Burst
(load bearing brick)
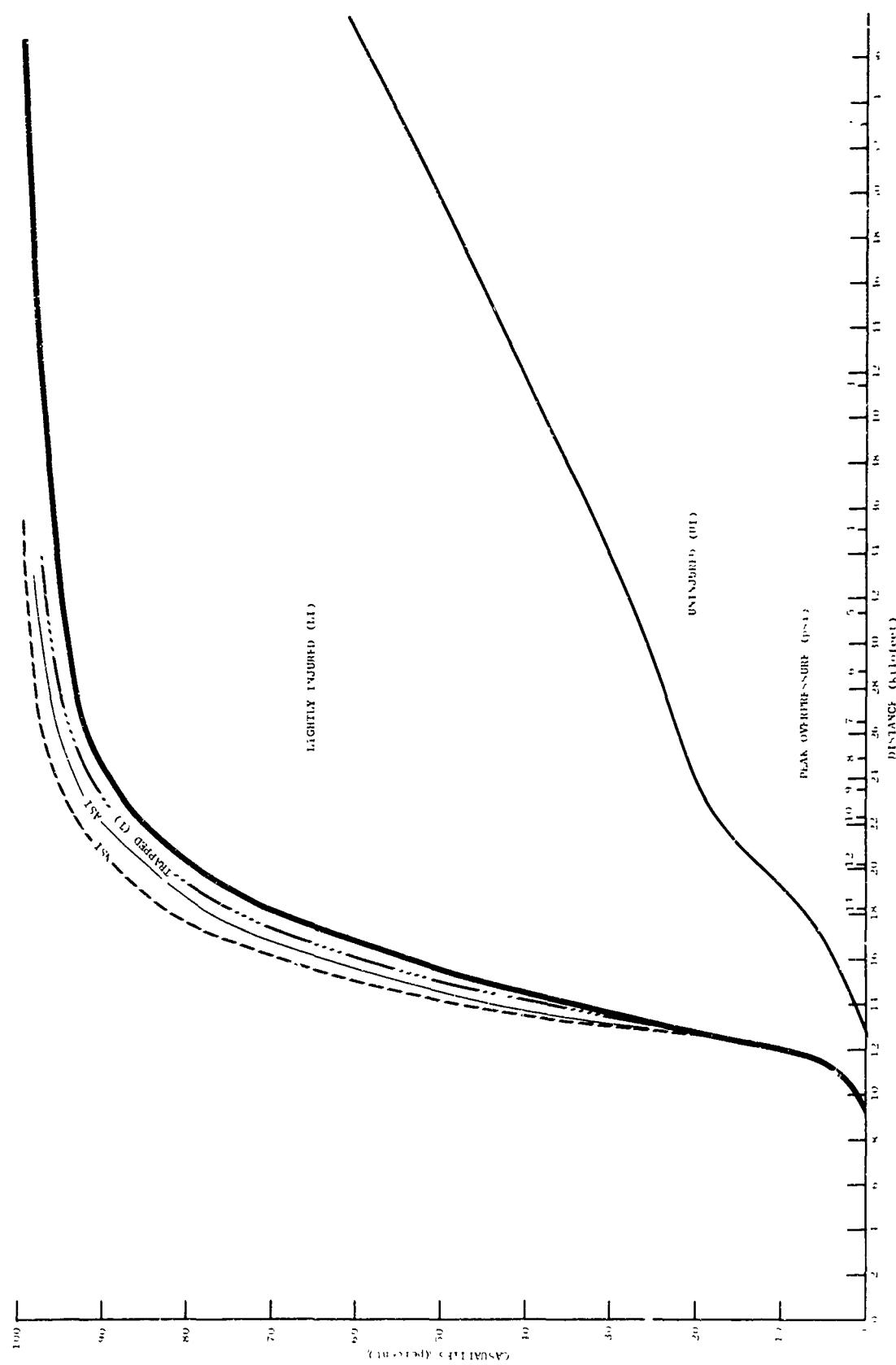
Fig. 18. Percent Casualties vs Distance for 10-Mt Surface Burst
(Japanese reinforced concrete construction)
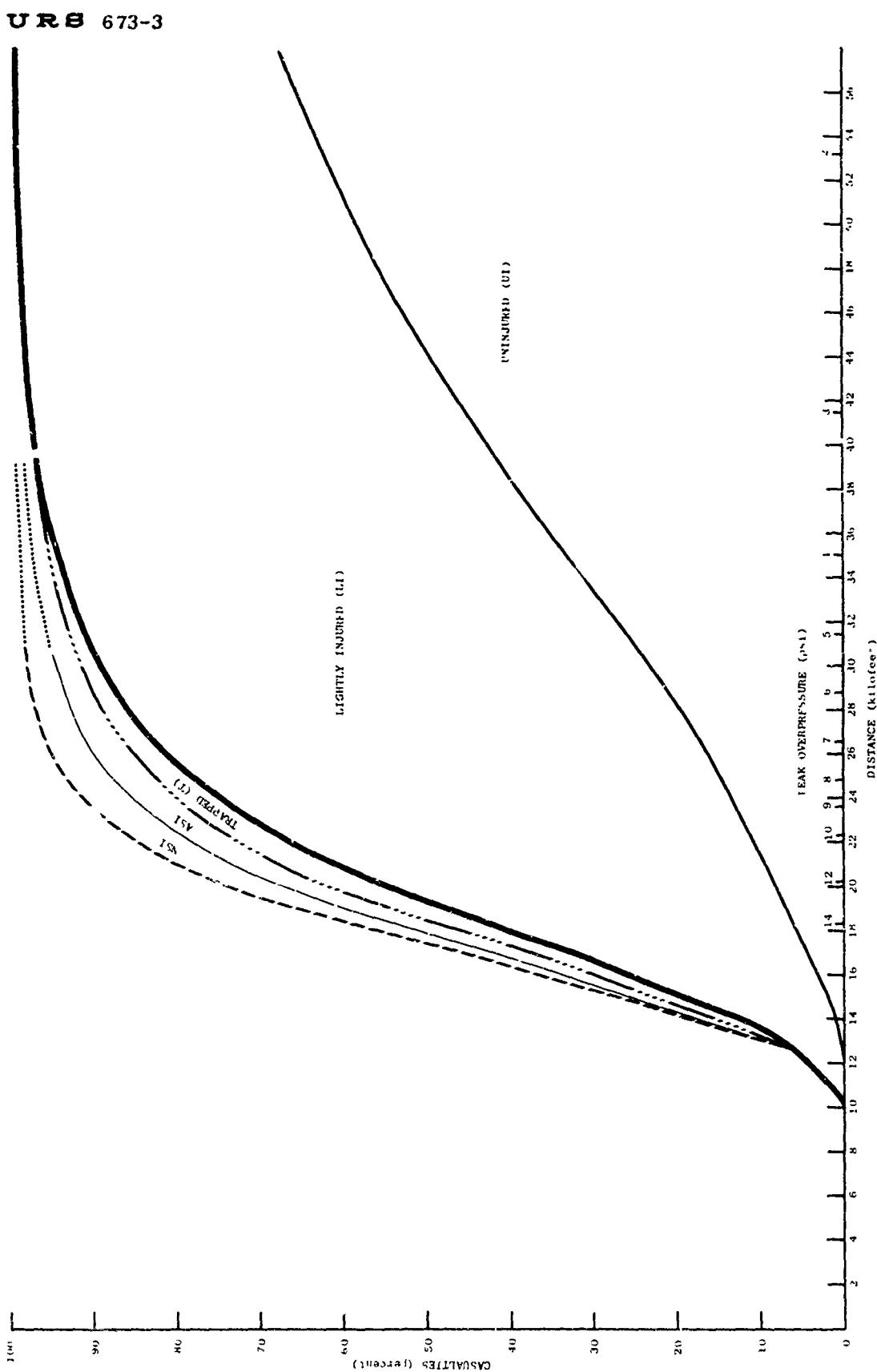
Fig. 19. Percent Casualties vs Distance for 10-Mt Surface Burst
(American reinforced concrete)
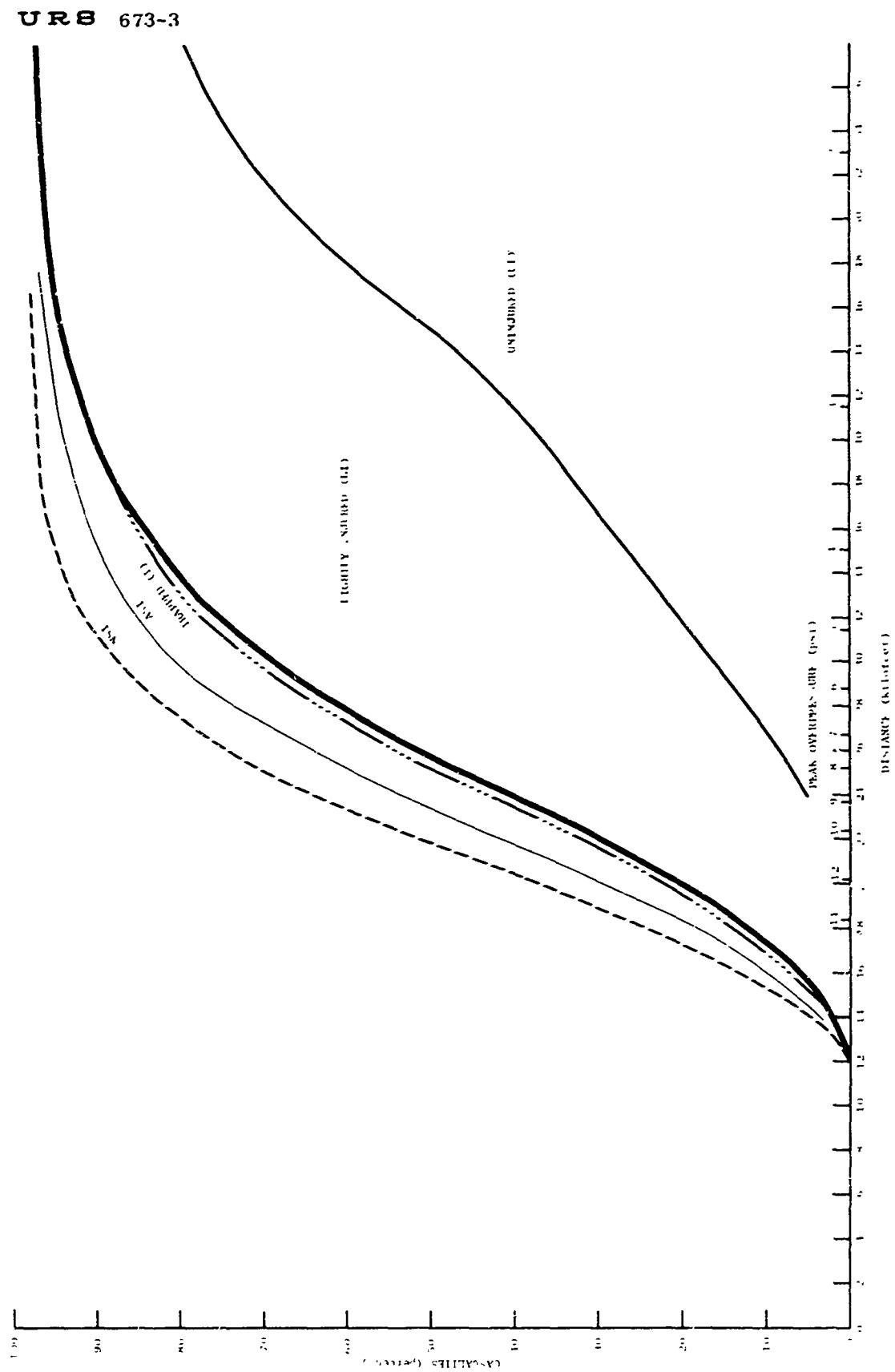
Fig. 20. Percent Casualties vs Distance for 10-Mt Surface Burst
(light steel frame mill construction)

URS 673-3
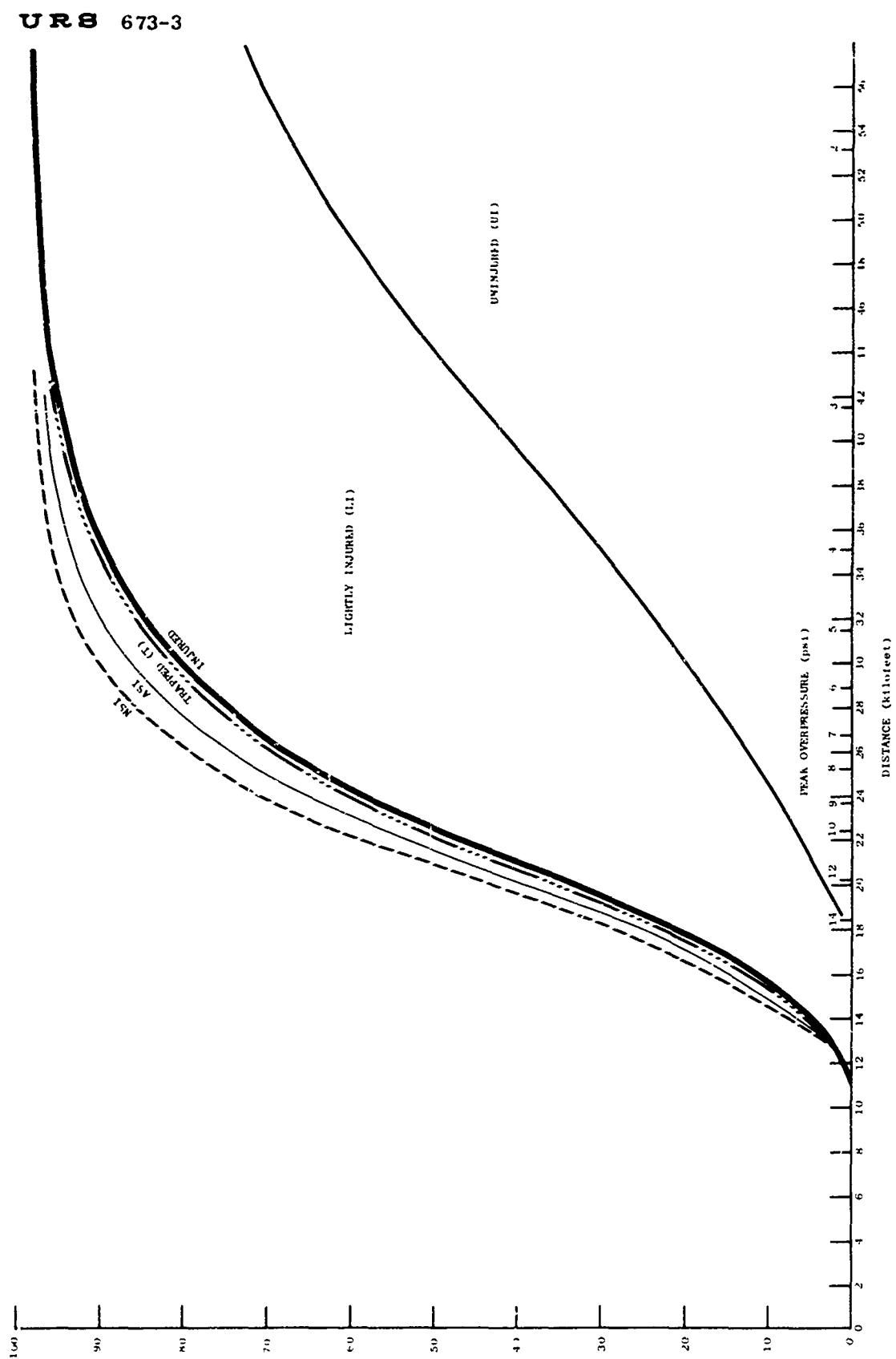
Fig. 21. Percent Casualties vs Distance for 10-Mt Surface Burst (heavy steel frame mill construction)

3. Light Steel-Frame Buildings (LSF). This category consists mainly of 1-story industrial types similar to those in the U.S., with relatively short spans and having sheet metal or corrugated asbestos siding.

4. Heavy Steel-Frame Buildings (HSF). This category is represented by 1-story heavy industrial "mill type" buildings of a height comparable to 3- or 4-story U.S. buildings. Sheet-metal or asbestos-cement siding were common in Japan.

5. Japanese Reinforced Concrete (JRC). These Japanese buildings were all-reinforced concrete multistory buildings (used for offices or public buildings) with integral roof slabs and wall panels. These buildings incorporated earthquake-resistant design and were generally stronger than most U.S. buildings which are not earthquake resistant.

6. American Reinforced Concrete (ARC). These buildings are similar to the JRC described above, but are not earthquake resistant.

Reference 10 provides a rationale for subdividing the total mortality values of Ref. 11 (values derived from mortality statistics from Hiroshima at the end of a 60-day period following the atomic attack) into the ASI, NSI, and T categories. Values for the uninjured category are simply derived by difference.

For megaton-yield weapons, the number of casualties from initial nuclear radiation is relatively unimportant compared with those from blast. Also, flash burns are minimal inside of buildings at the ranges of interest. Therefore casualties in a sheltered population are primarily due to blast effects, and can be scaled with distance reliably by the "cube-root law." (Actually, different exponents are used for different building types (Ref. 11)).

An important limitation of the data (as pointed out in Ref. 10) is that lethal stem fallout did not occur in Japan. Further, the fire radius is much greater for large weapons, making it difficult for ambulatory survivors to move far enough in the time available to escape the fire, as they did in the kiloton attacks on Japan. The single mortality function of Ref. 11 therefore probably drastically underestimates the actual total mortalities for large weapon yields. However, for purposes of evaluating

the effectiveness of firefighting activities and rescue operations in a local area in the first hour or so after an attack. the data would seem to be appropriate.

Rescue Effort and Performance

Although a simple measure of performance, such as the number of survivors rescued by direct action of the fire services, might seem desirable, such a measure does not take into account the prognosis for recovery of those rescued. Criteria for judging the effectiveness of the rescue effort are discussed in the next section, and it is concluded that effectiveness is to be measured in terms of rescued survivors who will ultimately recover from their injuries. Therefore the condition of the rescued survivors must be specified. In Table 1 the rescuees are divided into 10 categories (i = 1, 2, . . . 10) according to their condition immediately after the attack. Although the data are not in hand, Table 1 indicates symbolically the average effort (in man-hours) required to perform the various tasks. For example, $E^R_{i,j}$ represents the average number of man-hours required to release from entrapment a survivor whose condition is designated by i and whose location is designated by j. The total effort required to rescue this survivor is given by the sum

$$E_{i,j} = E^S_{i,j} + E^F_{i,j} + E^R_{i,j} + E^T_{i,j}$$

where S, F, R, and T refer to search, first-aid, release, and transport, respectively.

Effectiveness Criteria

Not all of the rescued survivors in each category will recover from their injuries. Let $P_i(\tau)$ be the prognosis for recovery (expressed as a probability ranging from 0 to 1) of a survivor who was in the ith condition immediately after attack and subsequently went unattended for a period of time τ before being rescued The prognosis for recovery $P_i(\tau)$ can be expressed as the product of three probabilities:

Table 1

MANPOWER REQUIREMENTS FOR RESCUE OF SURVIVORS AT RISK, j^{th} LOCALE

MAN-HOURS REQUIRED FOR TASK

AVERAGE MAN-HOURS TO SEARCH	ASSUMED TO BE A CONSTANT FOR ALL SURVIVORS NOT TRAPPED					ASSUMED TO BE A CONSTANT FOR ALL TRAPPED SURVIVORS				
AVERAGE MAN-HOURS FOR FIRST-AID IN FIELD	0	$E^F_{2_j}$	$E^F_{3_j}$	$E^F_{4_j}$	$E^F_{5_j}$	0	$E^F_{7_j}$	$E^F_{8_j}$	$E^F_{9_j}$	$E^F_{10_j}$
AVERAGE MAN-HOURS FOR RELEASE	0	0	0	0	0	$E^R_{6_j}$	$E^R_{7_j}$	$E^R_{8_j}$	$E^R_{9_j}$	$E^R_{10_j}$
AVERAGE MAN-HOURS FOR TRANSPORT TO SAFE QUARTERS	$E^T_{1_j}$	$E^T_{2_j}$	$E^T_{3_j}$	$E^T_{4_j}$	$E^T_{5_j}$	SAME AS FOR THE 5 CATEGORIES TO LEFT				
TOTAL MAN-HOURS REQUIRED TO EFFECT RESCUE	E_{1_j}	E_{2_j}	E_{3_j}	E_{4_j}	E_{5_j}	E_{6_j}	E_{7_j}	E_{8_j}	E_{9_j}	E_{10_j}

SURVIVOR'S CONDITION JUST AFTER ATTACK

CATEGORY, i	1	2	3	4	5	6	7	8	9	10
NOT TRAPPED	X	X	X	X	X					
TRAPPED						X	X	X	X	X
UNINJURED	X					X				
LIGHTLY INJURED AMBULATORY		X					X			
LIGHTLY INJURED NON-AMBULATORY			X					X		
SERIOUSLY INJURED AMBULATORY				X					X	
SERIOUSLY INJURED NON-AMBULATORY					X					X

1. Probability of recovery, from original injuries only, after waiting
   a period of time T for rescue

2. Probability of recovery from radiation exposure received while
   awaiting rescue

3. Probability of recovery from fire-inflicted burns received while
   awaiting rescue

Figure 22 illustrates the manner in which prognosis for recovery depends
on delay in effecting rescue for different casualty categories.
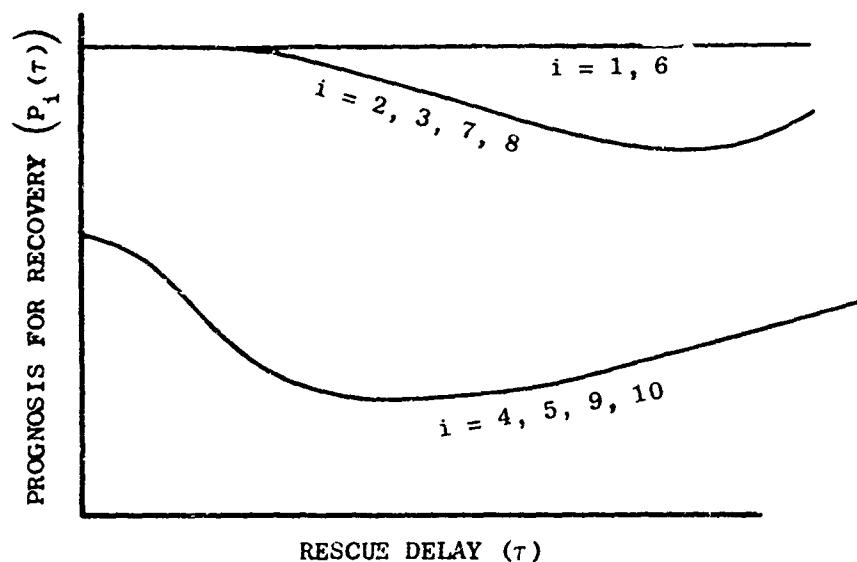
Fig. 22.   Prognosis for Recovery vs Rescue Delay

The illustration applies to cases where fallout and fire do not constitute continuing
threats and where adequate medical care is available following rescue.

Once a survivor is delivered to safe quarters the rescue is accomplished, and
consideration of the medical treatment received thereafter is not included in this
investigation.

The ratio

$$\frac{E_{i,j}}{P_i(\tau)}$$

gives the average effort (in man-hours) required to rescue a survivor who was in the ith condition and j^{th} locale immediately after attack and will subsequently recover from his injuries.

If the surviving resources of the fire services are not adequate to perform all of the damage control and rescue tasks demanded of it, then they must be distributed among the various tasks and locales within the stricken area. The distribution of surviving manpower will be a function of (1) time, (2) location, and (3) task to which assigned. Although somewhat artificial, it is useful to define the assignment of manpower to the rescue mission in the following way:

$M_{i,j}(\tau)$ = manpower (number of men) assigned to rescue of survivors in i^{th} condition and j^{th} locale

This variable is a..o a function of elapsed time since attack, τ. The rescue rate

$\dfrac{P_i(\tau) \times M_{i,j}(\tau)}{E_{i,j}}$ = rate of rescue (number per hr) of survivors in i^{th} condition and j^{th} locale who will recover, which may be

integrated with respect to time to yield the number of survivors (i^{th} condition, j^{th} locale) who have been rescued by time t and will subsequently recover:

$$N_{i,j}(t) = \frac{1}{E_{i,j}} \int_{\tau=0}^{\tau=t} P_i(\tau) \times M_{i,j}(\tau) \, d\tau.$$

Summing over all i

$$N_j(t) = \sum_i N_{i,j}(t)$$

and over all j

$$N(t) = \sum_{j} N_{j}(t)$$

gives the total number of survivors who have been rescued by time t and will subsequently recover.

Although the actual number of survivors requiring rescue after nuclear attack is ill-defined, the estimates generated by the analysis will be exact, and it is on this basis that the performance of the rescue effort will be evaluated. If $P_i(O)$ is the prognosis for recovery of a survivor in the ith condition who was rescued immediately after attack, then multiplying the total number of survivors in the ith condition by $P_i(O)$ yields the maximum number who might subsequently recover from their injuries. Summing this product over all survivor conditions and locales yields the total number of "rescuable" survivors.

The fraction of "rescuable" survivors who are actually rescued and subsequently recover is one measure of effectiveness which could be adopted for evaluation of the fire service's performance of the rescue function.

Equipment Requirements

The organization and equipage of light- and heavy-duty rescue squads is set forth in OCD directives (Ref. 33). These specifications form a basis for evaluating and/or improving the equipage of fire services for rescue work. They do not, however, take the following into account:

1. Demands for heavy-duty engineering equipment such as bulldozers, powered shovels, etc., which might be required to clear streets and assist in extricating trapped survivors.

2. Demands for fast transportation (trucks, buses, etc.) of large numbers of survivors to safe quarters.

These services might be provided by units of the proposed Emergency Operations Systems (Refs. 29 and 34), in which case the distribution of fire-service resources would be considerably altered.

The capability of the fire services to perform the rescue task is believed to be limited by the availability of manpower rather than equipment and therefore the distribution of manpower will be stressed in the analyses, with due consideration being given to the proper outfitting of available personnel.

Section 6

ANALYSIS OF FIRE-SERVICE PERFORMANCE

The evaluation of fire-service performance logically divides itself into two parts. First, it is necessary to estimate the level of performance without attempting to assign a measure of worth to that performance. Thus the application of a given level of effort in manpower. equipment. and resources can be estimated to produce certain results in saving lives and resources under a given set of conditions. Section 5 of this report develops analytical expression for some of the relationships between threat, demand, resources available. and performance that are required for estimating performance. Second. these accomplishments must then be evaluated relative to certain standards of performance (or criteria of effectiveness) which are derived from the ranking of importance of the objectives achieved. In other words, it is necessary to evaluate how effective the performance was in accomplishing various objectives in order of their importance. The following discussion treats this. the second aspect of the analysis.

ASSESSMENT OF DEMAND PRIORITY

In order to formally analyze the performance of fire services, it is necessary to have a rationale for allocating services (or response) to demands. Some responses are quite automatic and not determined by objective appraisal. These are largely the responses that occur immediately following the receipt of direct effects of the detonation. But it can be assumed that within a short period of time the responses will become organized and controlled in a way that is determined by a rational process of appraisal and decision making. While the decisions may be based on inaccurate appraisals, which in turn are derived from incomplete (or erroneous) information, certain basic rules will consistently govern the choice of action. Therefore, in both

specifying the logical demand/response actions and evaluating the effectiveness of performance, a realistic ranking by importance of the objectives is needed.

Categories of Demand

There are four broad categories of demand encompassing all possibilities. These may be described as follows:

1. Protecting survivors by neutralizing or removing the threat

2. Protecting resources by neutralizing or removing the threat

3. Removing survivors from threats that cannot be neutralized

4. Removing resources from threats that cannot be neutralized

The threats, as we have seen, are of several kinds; but because of the specialized capability of the fire service, fire is considered to be the threat of primary concern to the fire service. Therefore, the primary function of the fire service in (1) above is firefighting wherever people's lives are in jeopardy because of fire, and in (2) it is firefighting to save property threatened by fire. The latter will ordinarily be a byproduct of (1) except in cases where a resource is so vital to survival as to warrant special attention or where there are no lifesaving demands. Many of the actions included in (3) are properly termed rescue, but this category also includes the broader concepts of evacuation and remedial movement. The actions in (4) are rarely expected to be performed by anyone, much less fire-service personnel. Exceptions, such as removing food stuffs, medical supplies, and other survival goods from stores, warehouses, and hospitals threatened by fire, might be performed by civilian volunteers at the direction of civil defense authority. For the most expedient use of professional manpower, the role of the fire service in (4) should be limited to forecasting the threat and apprising the higher echelon authority of it. Therefore, the demands which will require most of the action by the fire services are in categories (1) and (3).

It might be more accurate. then. to refer to their actions as rescue. evacuation support. and firefighting to protect survivors. with damage control being primarily a byproduct of their eff 's. We have found it to be both logical and analytically convenient to distinguish those activities of the fire services which are casualty-limiting from those which are purely damage-limiting. rather than to distinguish rescue from damage control. Thus all firefighting actions which remove a threat to the surviving population. as well as rescue and evacuation activities (which remove the survivors at risk from the threat). are taken together as casualty-limiting activities. and their payoff is measured directly in added survivors. By the same token. any actions which remove a threat to resources and vice versa without directly influencing the immediate survival of the population. are considered separately as damage-limiting activities.

Allocation of Demand Priorities

The principal responsibility of the fire services is the protection of survivors of the direct effects of the attack who are in immediate jeopardy from one or more of the residual hazards. such as fire. local fallout. or imminent collapse of blast-damaged structures. Because of their specialized training and equipment. the fire services generally stand in a better position to provide protection from fire than from the other hazards. but they have the capability to deal successfully. in varying degrees. with all threats to human life. Part of their primary obligation is to rescue and implement the relocation or evacuation of survivors from situations which are. or are likely to become. untenable because of the fire threat.

Their se~ndary obligation is to protect the lives of survivors from longer range threats and to protect and maintain life-support facilities and resources. Longer range threats include the spread of fire from adjacent or remote areas. fallout from distant detonations. and entrapment of survivors so that they cannot obtain necessary sustenance and medical aid. The life-support facilities include fallout shelters. fire-safe open areas. multipurpose staging areas. hospitals. etc. Life-

support resources include medical supplies, food, water, and vehicles for evacuation and remedial movement.

Lastly, the fire services have a responsibility to save property, notably that which may be needed for long-term survival and recovery. This category includes food and water supplies, shelter from the natural environment (e.g., homes, apartment buildings hotels, clothing and other fabric supplies) fuel supplies, essential transportation, and essential utilities.

As indicated previously, both the demands and the feasible fire-service responses to them are contingent upon initial damage and continuing threats. A small number of representative threat contingencies can be derived from a set of operationally distinct situations, such as the basic operating situations of Ref. 1, and for each contingency a priority listing of feasible responses can be established. This would be a worthwhile objective of additional research.

Measures of Performance

The ultimate measure of performance is added survivors. All of the activities of the fire services, however, do not directly result in added survivors, although the basic long-term motive of any response is to increase survival; and property saved, either intentionally or as a byproduct of a lifesaving activity, should be considered as additional performance. In terms previously introduced, casualty-limiting activities may incidentally result in property saved, wherea; damage-limiting activities are motivated by the recognition of a need for protecting life-support resources for the immediate and long-term survival of the population. Some immediate survivors of the direct effects of a nuclear attack wi'l be so severely injured that their prognosis for recovery is low, and any effort given to saving their lives from imminent danger might appear to be unprofitably expended. The fire services will act in such matters on the basis of general or specific guidance from higher authority. On the other hand, in evaluating performance, added survivors with a favorable prognosis for recovery

must be weighted more heavily than those which will probably die of their injuries. A method of weighting was developed in the previous section of this report.

The foregoing factors do not complicate the evaluation of performance until comparisons are attempted between alternative accomplishments for the purpose of choosing the more effective system of response. In other words, performance can be simply expressed in terms of the subtotals of survivors added and resources saved.

THE FORMALIZED PERFORMANCE MODEL

In this subsection we present the basic concepts from which a formal model of fire-service performance could be developed. We conceive of the model as being one which could be either manually performed or programmed for machine computation. In general, operations which can be done routinely by hand can be readily programmed for digital computers. Our approach has been to construct the model with the manual operation in mind, while remaining aware of its possible conversion to computer format at a future date. The model is intended to accomplish the following:

1. Predict blast damage, initial fires, and casualties due to weapon effects.

2. Predict fire distribution with time as a measure of threat to the surviving population and resources.

3. Estimate changes in fire threat resulting from fire-service activities.

4. Provide a basis for changing tactics with changes in threat/demand.

5. Estimate conditions corresponding to uncontrollable fires as criteria for evacuation.

6. Estimate losses in initial survivors from abandonment and exposure to extra shelter hazards during evacuation from untenable fire situations.

7. Estimate additional survivors and resources saved by the actions of the fire service.

Basically the procedure is to simulate an urban complex by describing in appropriate form the characteristics of the urban area which are significant to, or can be modified in one way or another by, fire-service action. This requires two levels of detail: (1) broad generalizations required to describe the <u>overall</u> damaged target and (2) fine-structured descriptions of relatively small areas of operation. The distinction between the two, both in characteristics and application, will be made clear in subsequent discussion.

Performance is measured by the differences in casualties and resources destroyed between a "no-action baseline" and as estimated for the various forms of fire-service action. Therefore, the performance model is basically a "perturbed damaged-target model," but, as we shall see, it is not necessary to describe the entire damaged target in detail. In fact, a great deal can be learned about fire-service capabilities from studies of their performance in small "isolated" segments of the total urban complex.

It is convenient to divide the performance model into several submodels. The first of these is an overall damaged-target model. It is not within the scope of this project to develop damage-assessment procedures, but the output requirements need to be specified so that in choosing from existing procedures a compatible method will evolve.

The purpose of the damaged-target model is to provide a complete picture of (1) demands for fire services — their kinds, numbers, and locations, (2) degradation of the fire service — its personnel casualties, losses in equipment, and losses in necessary resources (especially water supplies), and (3) obstacles and impediments to fire-service response. To keep the input detail and damage-assessment effort within bounds consistent with the needs of the problem, the simplest practical form is used as a starting point, with characteristics and detail added only as required.

The simplest form of a damaged-target model that is satisfactory for fire-service analysis is one that broadly describes structural damage by blast and fire, that is, one that displays zones of (1) total destruction, (2) significant structural

collapse and heavy debris. and (3) light blast damage: and presents for each zone. both initially and at intervals of time. the distribution of fires expressed in terms of the fraction of structures actively burning and burned out. To assess damage with this limited level of detail. all that is required is a description of the urban complex in terms of land-use areas and general building construction types and an "overlay"[*] of weapon-burst characteristics.

A considerable simplification in the damaged-target model can be achieved while retaining utility by making use of a set of basic damage categories similar in form to the various basic operational situations described in Ref. 1. Although this does not replace the need for damage assessment procedures. it does provide a set of distinguishable operational situations for which separate submodels must be constructed. For example. there are several qualitatively different transattack and immediate-postattack environments. described in Ref. 1 as HIFIRE, LOFIRE, NEGFIRE, HIRAD. LORAD, and NEGRAD, which in combination with one another form a set of nine categories representing recognizable. operationally distinct situations that could exist following nuclear attack. As they apply to fire-service operations. some of these are redundant. Some of them are subject to change from one to another and should be modelled accordingly. However, only a few changes in state with time are logically allowable or operationally significant. As a result, there is a small number of operationally distinct situations that require modelling.

The description of the model to this point has purposely neglected the population distribution and the disposition of fire-service forces. because it is desirable to treat both of these as variable initial conditions and because once they are specified. those portions of the damaged target which must be described in greater detail are thereby specified.

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[*] The term overlay is used in the figurative sense of applying weapon effect contours to a map of the urban target. This is a perfectly satisfactory manual procedure, however, and has a machine analogue in a program which makes use of "cells" whose coordinates and characteristics are enumerated as input conditions. (See, for example. Ref. 35.)

In concept the model can be applied to either a warned or an unwarned population. We will concern ourselves only with warned postures of which, at the present, there are basically three kinds — the NFSS, the warned-resident, and the movement-to-shelter postures. The deployment alternatives for the fire-service forces are many, but basically they group into two categories — those which are consistent with the "inside-out" concept of operations and those of the "outside-in" variet".

The fire-service employment can be simulated at various preattack levels of manpower and preparedness and with a variety of strategies. As limited by the scope of this study, we consider only current (or typical peacetime) levels, with the result that the cost factor remains relatively fixed. Strategies are those for preattack warning, with the assumptions that choices of tactics for specific demands are clearly established beforehand as a set of contingency plans and that responses to demands are automatic and correct.*

Whereas the number of possible strategies that might be employed by the fire services is very large and highly variable, intuition suggests that a few basic strategies adequately describe most situations, that is, they encompass the major effects of strategy on performance. Example strategies are as follows:

- Concentrate on lifesaving (mainly relocation and rescue) activities, with firefighting done only as incidental to saving lives.

- Fight fires from "islands of resistance," which consist of selected buildings or clusters of buildings that serve as personnel shelters or that house critical resources, for the purpose of protecting the contents of those buildings.

- Fight fires along certain perimeters to limit and/or prevent spread of fire.

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*The appraisal of demands is assumed to be based on "perfect" information, that is, accurate in detail. It may, however, be limited in scope, e.g., local and current information only.

- Use elements of the general untrained population. in conjunction with small. mobile. lightly equipped brigades of professional firemen. to extinguish initial fires while they are small.

- A mix of two or more of the above strategies.

The next step to the procedure distributes the population over the simulated urban complex according to one of the warned postures and calculates the initial distribution of casualties and its changes with time through the early postattack period and on into the late postattack or recovery periods to provide a "no-action baseline" from which to measure fire-service accomplishments. Such a procedure has previously been proposed and the concepts developed in a recent URS report (Ref. 35) as a way of evaluating the effectiveness of support-systems countermeasures. For the problem at hand, however, a comprehensive inventorying of casualties over an entire urban target seems unnecessary. With the limited capabilities of existing fire services, a large part of the "baseline" toll in casualties will be unaffected by their best efforts. Since we are only concerned with survivors as a result of the activities of the fire services, and not with total numbers of either casualties or survivors, we need only consider that part of the population which will be directly affected by fire-service action.

A simplifying aspect of the model, then, is that there are relatively few fire-service units within a metropolitan area, and each of these units has a limited range of operations, particularly in initially damaged areas. Therefore , the next step in the analysis is to "deploy" the limited number of fire-service units to their preattack locations, estimate their casualties, losses in equipment, and loss in mobility (due to blast damage to mobile equipment and to debris levels in the streets of their locale) and availability of water and other resources. Using these estimates, bounds can be placed on the area and mode of operation of each surviving unit. Within each of the bounded areas of operation, an enumerable set of demands can be ascertained from the conditions of the attack and the detailed characteristics of the area. For example it will be necessary to know which buildings have large concentrations of survivors

(locations of fallout shelters) which buildings house vital resources (we would expect the fire-service units to be in or near these at the time of attack for the "inside-out" deployment), where the major fire breaks and major routes of travel are, which buildings have fires, and what the number and distribution of these fires are. Needless to say, the information requirements for these areas of operation are much more stringent than were those for the overall damage assessment.

In applying the model, responses are determined by the priority order of the set of demands which are ordered in relation to immediacy of the threat and numbers of survivors at risk, with direct threat to life always of higher priority than threat to survival resources. Thus a hazardous fire in an occupied shelter structure would be a higher-order demand than a fire within the same block as the shelter and it, in turn, would be of higher priority than a destructive fire in a medical-supply warehouse.[*] Guidelines for the ordering of demands were given in an earlier part of this section. The set of demands will of course change with time.

For each member of the set of demands for the operational area there is a corresponding response. Each response is divided into a travel time and an activity time. Within the operational area there will typically be more than one demand having the same priority. For such cases the one with the shortest travel time would be chosen. Thus the demands would be serviced in order according to immediacy of the threat, proximity to the fire-service unit, and potential payoff in lives saved; and the performance of the fire-service activity would be measured as a function of time in terms of the lives and resources saved through successful response to demand. The compatibility of these concepts with the queuing methods of machine computing are readily apparent.

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[*]This method of ordering demands works best for the situation of a fire-service unit in the midst of a fire-involved area. We can conceive of cases where abandoning some shelters to an immediate threat to hold a fire line would have a greater long-range payoff. This is a basic consideration in the choice between "inside-out" and "outside-in" strategies, whose evaluation is a principal concern in evaluation of fire-service capabilities.

The formalism of approach given in the preceding paragraphs should be tempered by considerations of reality and a generous measure of common sense. We know, for example, that in emergencies of the sort we are attempting to simulate fire-service units would not respond in a completely logical or orderly way. partly because they would not have all the information necessary and partly for reasons of human error. There appear to be compensating factors, however. Consider the extreme examples of a fire-service unit located in an area heavily impacted by weapon effects and another located outside of the area of initial effects. The first would have lost some of its organizational structure and possibly all communications with the outside, but the demands on it should be rather obvious. The second would be uncertain. initially, of the nature and location of demands to which it should respond. but it would retain undegraded facilities, including mobility and communications.

CASE STUDIES

Results of this study to date point to the desirability of a case-study approach to defining the special problems associated with different levels of initial weapon effects. Such case studies could by themselves provide answers to the question—under what conditions are fires uncontrollable by the actions of the fire services, i.e., when should they give their full attention to rescue and relocation of survivors? Beyond that they could serve as operational-area submodels for the formalized performance model.

The cases should be chosen to represent a range of effects from severe blast damage and high fire incidence to no substantial initial effects. Important distinctions, such as those between areas of different land use and between surface bursts and air bursts, should be reflected in the choice of case-study conditions. As part of the project reported here, two case studies were performed for the San Jose central business district. The details are given in Appendix A.

Section 7
RESULTS AND RECOMMENDATIONS FOR FUTURE WORK

Because of the nature of the material reported here, many of the findings
cannot be grouped into a "Results" section without considerable repetition of material
which has gone before. Virtually the entire report represents a development of
concepts and methods which are the essential results of the study. With this in mind,
we will present here only those results which have not appeared to this point and then
discuss applications of the results of the whole project to future research and
operational planning, pointing out attractive approaches to additional research.

RESULTS OF CASE STUDIES

The case studies are described in Appendix A. An example central business
district was selected and its blast and fire response evaluated. Its population was
assumed to be sheltered, and the fire services were assumed to be deployed to shelter
buildings. Two attack configurations were analyzed, viz., air bursts located at
distances from the central business district such that overpressures of 2 and 5 psi
would be experienced. These were chosen to be representative of controllable and
uncontrollable fire situations, respectively.

The first case study did in fact turn out to be one in which fires could be
controlled if about 10 percent of the sheltered population augmented the professional
force by applying prompt and effective self-help attention to the initial es in the
shelter buildings and the other buildings within the same blocks as th   elters.
According to the analysis, all of the other fires in the area could be ex   guished (to
the point where firefighters equipped with hand-operated devices — either the excess
fire department personnel or nonprofessionals — could successfully overhaul the
residual combustion) within less than an hour and a half following the detonation.

After this period. mobile equipment and crews could turn to the job of holding fire fronts nearer ground zero.

In the second case study, the fire situation that develops within an hour after detonation has many of the earmarks of a firestorm. Regardless of whether it closely resembles the Hamburg fire, it is clearly uncontrollable, and virtual. the entire sheltered population would have to relocate. The decision to relocate could probably be made within a few minutes following air blast arrival, but, according to a recent analysis by Condit (Ref. 36) of the evacuation of the same area in the face of an untenable fire threat, some parts of the area are too remote from safe refuge for the threatened population to effect escape before the fire environment in the open becomes too hostile for survival.* If this were so, the fire service would be of little aid in a situation where water is unavailable for providing protection to the refugees and debris levels are so high as to prevent vehicular mobility. On the other hand, considerable safety from fire would be afforded by the parks and open spaces of the area if a more conventional area fire developed. The fire service equipped with hand-operated devices could perform effective activities in connection with remedial movement to these areas and protection of the areas from fire spread.

Both case studies indicate deficiencies in the analytical methods used. Methods are required for estimating fire-spread probabilities for distances between buildings which are greater than dimensions of buildings and the rate and likelihood of spread of fire through contiguous clusters of buildings. The corresponding fire-control activities and their analytical performance relationships are also needed. Lack of reliable information regarding the basis for predicting formation of firestorms and on the characteristics of the environment they create prevents us from assessing the habitability and fire security of potential refuges in the midst of uncontrollable area fires.

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*This assumes a Hamburg-like firestorm. and we have some serious reservations about the justification of this assumption.

Although the case studies successfully represented situations of controllable and uncontrollable fire, they contributed little toward an unambiguous definition of these situations because they were so different from one another. The 5-psi case was uncontrollable for a number of reasons, any one of which by itself might be enough. The 2-psi case might be considered marginally controllable because its outcome depended heavily on the level of control effort, especially on self-help response. In spite of this, we can conclude that fires in an area of the sort studied would have a threshold of "inherently uncontrollable" fire somewhere between 2 and 5 psi (for the given conditions of attac) and that this threshold is probably much nearer 2 psi than 5 psi. In fact, the principles illustrated in Fig. 3 suggest that fires in a heavily built-up area may be beyond control capability at a distance where as little as about 20 percent of the structures are initially ignited. For the conditions of the case study this would be about 11.7 miles from ground zero or about where overpressures of 2.4 psi would occur.

APPLICATIONS OF RESULTS OF THIS PROJECT
AS GUIDANCE TO OPERATIONAL PLANNING

The results of this study support the views advanced in Ref. 1 that (1) the overriding constraint on emergency operations in an urban environment following nuclear attack is fire and (2) planning for emergency operations must be contingent upon fire controllability. Since the distinction between controllable and uncontrollable fires will serve as a basis for decision about critical operational objectives and tactics, not only for fire services but for all other emergency services as well, the need for a re' ble, operationally effective definition of controllable and uncontrollable fires is compelling. The current Concept of Emergency Operations (Ref. 1) is inadequate in this respect. The two conditions are simply described as follows:

> CONTROLLABLE FIRES - Scattered fires subject to potential control

> UNCONTROLLABLE FIRES - Many fires beyond control capability

The distinction can be improved a little by adding the phrase "to the extent that most
of the population can be protected" to the definition of controllable fire, but we are
still left with the problem of predicting the magnitude of the fire threat and estimating
the extent to which its development can be affected by fire-service action.

Whether an operational area is, or will become, an uncontrollable-fire area is
determined by (1) the fire vulnerability of the area (which can be ascertained in a
general way before the attack), (2) the fire density and distribution after attack, (3)
the weather conditions, and (4) the level of effort and prompt response of fire-control
activity. The inclusion of the fourth factor implies that concerted fire-control efforts
applied promptly and effectively at well chosen places can significantly alter the nature
of the threat. There is little doubt that this is so, and it is one of the objectives of a
study of fire-service capabilities to evaluate this potential. On the other hand, there
are fire situations which are "inherently uncontrollable" by any realistically conceived
fire-defense organization. These can be defined without regard to the makeup of the
fire defenses.

Grossly considered, there are two conditions of concern:

1. Conditions of high initial damage and high fire incidence that cause
   the area to quickly develop into a mass fire (or firestorm) by nearly
   simultaneous buildup of many initial fires and the rapid short-range
   spread of fire from building to building. *

2. Conditions of relatively light initial fire incidence in an area of high
   fire spread potential (either inherently or because of weather
   conditions) that is contiguous with (or proximate to) areas of high fire
   incidence.

Guidance for the recognition and prediction of untenable situations can be
provided to operational personnel from the results of research into the effects of
nuclear weapons and is, therefore, one way in which research can materially affect
the performance capability of the fire services. Unfortunately very little information

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*A fire of "high power density" in the Dikewood terminology. (See Ref. 3.)

has existed until quite recently for making a truly general and rigorous evaluation of the urban fire threat on which to establish operational guidelines. Criteria have been proposed for predicting the occurrence of firestorms. but neither the criteria nor the resulting hazards can be considered to be known with high reliability. Ongoing studies, such as those of Work Units 253-B and 253-C, are expected to provide a reliable basis for estimating fire incidence and spread. but so far the results are incomplete. Presently available guidance is summarized in this report (see Section 4).

Contingency plans for uncontrollable fire situations will have as their objectives (1) the protection of low-risk buildings and open areas from fire spread and other fire hazards and (2) the relocation of the surviving occupants of high-risk buildings. at the earliest recognition of an untenable fire threat. to areas of greater safety from fire. even if the new environment is radiologically hazardous.

In areas where fires are judged to be capable of control. the objectives of the fire services should be (1) to suppress all initial fires that directly threaten the sheltered population. making maximum use of volunteer help: (2) to establish fire-defense lines at appropriate fire breaks: and (3) to suppress fires that exceed self-help capability. but only if they pose an imminent threat to the surviving population and critical life-support resources. Again these objectives are to be accomplished even if a radiological hazard is present. Only in cases where the fire threat is negligible will the radiological environment serve to constrain fire-service operations. Within the limitations of the radiological constraint. fire services in areas of negligible fire threat will aid areas of higher demand to an extent consistent with the maintenance of fire security of their own area of jurisdiction.

RECOMMENDATIONS FOR FUTURE WORK

Most of the results reported here are incomplete or of an interim nature. The concepts of a formal method for evaluating fire-service capabilities to perform damage-control and rescue functions in nuclear emergencies have been established and many of

the performance relationships required for the method's implementation have been derived. It is strongly recommended, however, that, before additional effort is given to developing a highly formalized method of analysis, case studies of the sort described in the preceding section be conducted to better define its purpose and scope.

Ongoing research in other OCD Work Units is generating the required technology for delineating the factors that determine operational feasibility and fire-service demands. The results of these studies should be translated into guidance for operational planning. Notable among the requirements is the need for improved, unambiguous definitions of uncontrollable fire situations that wil' permit reliable recognition and forecasting of untenable fire threats to be made.

The performance relationships developed in this study can be applied to relatively simple optimization analyses of fire-service operations. The extinguishment rate concepts are particularly worthy of note. Analytical descriptions afforded by the equations developed during this research can be applied to determine the most advantageous distribution of manpower and equipment when the demands exceed available resources. This should be pursued in follow-on work.

Section 8

REFERENCES

1. Office of Civil Defense, Federal Civil Defense Guide, Part G, Chapter 1, Appendix 1 (Working Draft, June 26, 1967)

2. Martin, Stanley B., Fire Service Capabilities for Damage Control and Rescue, Quarterly Progress Report, URS 673-1, URS Corporation, Jan 20, 1967

3. Loumasson and Keller, Dikewood Corporation, DC-TN-1056.1, Dec 1966

4. Brunswig, Hans, Practical Experience of Fire Protection Services, Parts I and II, English Edition, Institute for Defense Analyses (translater under OCD Work Unit 4315A), June 1966

5. U.S. Strategic Bombing Survey, Fire Raids on German Cities, Report No. 193

6. Glasstone, S., ed., The Effects of Nuclear Weapons, Revised Edition, U.S. Atomic Energy Commission, April 1962

7. Edmunds, J. E., C. K. Wiehle and K. Kaplan, Structural Debris Caused by Nuclear Blast, URS 639-4, URS Corporation, Oct 1964

8. Rotz, J., J. E. Edmunds and K. Kaplan, Formation of Debris From Buildings and Their Contents by Blast and Fire Effects of Nuclear Weapons, URS 651-4, URS Corporation, Jan 1966

9. Van Horn, W. H., G. B. Boyd and C. R. Foget, Repair and Reclamation of Gas and Electric Utility Systems, (Work Unit 3311B) URS 669-6, URS Corporation, July 1967

10. Crain, John L., Robert K. Meister, Lacy G. Thomas and Eugene M. Spurlock, Supplemental Analysis — Civil Defense Rescue, Phase 1b Analytical (Draft) Report, Stanford Research Institute, Aug 1966

11. Davis, et al., Prediction of Urban Casualties from Immediate Effects of Nuclear Attack (U), Dikewood Corporation, April 1963 (C)

12. Martin, Stanley B., Development and Application of a Complete Fire-Behavior Model, (OCD Work Unit No. 2538C) URS 674-3, URS Corporation (in preparation)

13. Cohn, B. M., L. E. Almgren and M. Curless, A System for Local Assessment of the Conflagration Potential of Urban Areas, (OCD Subtask 2538A) Gage-Babcock & Associates, Inc., March 1965

14. Varley, R. B. and G. L. Maatman, Shelter Fire Vulnerability — A Survey and Analysis of Representative Buildings, IITRI, March 1965

15. Foget, C. R., R. D. Bernard and W. H. Van Horn, Final Systems Analysis for EOSD Engineering Programs, URS 672-10, URS Corporation, March 1967

16. Salzberg, F., G. Maatman, and F. Vodvarka, An Approach to Trans-Attack Fire Suppression in Urban Areas, IITRI N-6005, March 1964

17. Varley, R. B., and G. L. Maatman, Shelter Fire Vulnerability — Specific Fire Limiting Activities for Occupants, IITRI N-6005, Sept 1964

18. Salzberg, Labes, Nielsen, and Waterman, Prediction of Fire Damage to Installations and Built-up Areas From Nuclear Attack — Study of Initiation and Spread of Fires in Typical Structures, IITRI, Dec 1960

19. Salzberg, Gutterman, and Pintar, Prediction of Fire Damage to Installations and Built-up Areas From Nuclear Weapons, Final Report — Phase III, Theoretical Studies, IITRI, July 1965

20. Labes, William G., Fire Department Operations Analysis, NRDL-TRC-55, (OCD Work Unit 2522F), Sept 1966

21. Law, Margaret, Heat Radiation From Fires and Building Separation, Fire Research Technical Paper No. 5, Department of Scientific and Industrial Research and Fire Office's Committee Joint Fire Research Organization, London, 1963

22. Martin, S. B., and N. J. Alvares, Ignition Threshold for Large-Yield Nuclear Weapons, USNRDL-TR-1007, April 1966

23. Perry, John H., ed., <u>Chemical Engineers' Handbook</u>, 3rd Ed., McGraw-Hill Book Company, Inc., New York, 1950, p. 1174

24. Arnulf, et al., "Transmission by Haze and Fog," <u>J. Opt. Soc. Am.</u>, Vol. 47, No. 6, 1957, p. 497

25. Defense Atomic Support Agency, <u>Capabilities of Nuclear Weapons, Part II — Damage Criteria (U)</u>, TM-23-200, 1962 (C)

26. Shaw and McNea, <u>Exposure of Mobile Homes and Emergency Vehicles to Nuclear Explosions</u>, WT-1181, Federal Civil Defense Administration, 1957

27. Meister, Robert K., <u>Damage Assessment Analysis</u>, Stanford Research Institute, Dec 1965

28. Meister, R. K., et al., <u>EOSD Phase I Working Paper on Civil Defense Rescue — Analytical Report</u>, Stanford Research Institute, Aug 1965

29. Jenkins, J. E., R. H. Thornton and E. R. Brooks, <u>Remedial Movement</u>, Revised Draft: Phase I Analytical Report, Emergency Operations Systems Development Program, Task No. 6, Research Triangle Institute, Dec 1965

30. Lee, H., <u>Estimating Cost and Effectiveness of Decontaminating Land Targets, Vol. I, Estimating Procedure and Computational Technique</u>, USNRDL-TR-435, U.S. Naval Radiological Defense Laboratory, June 1960

31. Miller, Carl, <u>Fallout and Radiological Countermeasures</u>, Vol. 1, Stanford Research Institute, Jan 1963

32. <u>Design of Structures to Resist Nuclear Weapons Effects</u>, American Society of Civil Engineers, Manual of Engineering Practice No. 42, 1961, p. 27 (reproduced in Ref. 36)

33. Department of Defense, <u>Rescue Skills and Techniques</u>, FG-E-11.1 (formerly TM-14-1), Office of Civil Defense, Dec 1963

34. Van Horn, W. H., C. R. Foget, R. L. Fuller, and M. B Hawkins, Emergency Operations System Development, Phase I, Analytical Report — Engineering, <u>Analyses for EOSD Engineering Programs</u>, URS 657-7, URS Corporation, Dec 1965

35. Hawkins, Myron B, Conceptual Development of an Analytical System for Evaluating Alternative Civil Defense Countermeasures, (OCD Work Unit 2312A) URS 667-4, URS Corporation, June 1966

36. Conlit, R. I., Area-Wide Shelter Systems, (OCD Work Unit 1631A), Project MU-4536, Stanford Research Institute, Dec 1965

37. Martin, S. B., M. Staackmann, and R. W. Ramstad, Supplementary Analysis of Fire-Service Capabilities for Damage Control and Rescue, (OCD Work Unit 2522E), URS 673-4, URS Corporation, March 1968

38. Rodden, R. M., F. I. John and R. Laurino, Exploratory Analysis of Fire Storms, Stanford Research Institute, May 1965

39. Office of Civil Defense Mobilization, Fire Effects of Bombing Attacks, TM-9-2, Sept 1955

40. McFarlane, C., Predicting Building Fire Production due to Nuclear Weapons Attack on Canadian Cities, Nuclear Tracers, Ltd., Toronto

41. Goodrich, David W., et al., Vulnerability of the Water, Sewage, and Drainage Systems in San Jose, (OCD Work Unit 4334A), Project MU-4949-390, Stanford Research Institute, Oct 1967

Appendix A
CASE STUDIES

Two case studies are reported here[*] which were chosen to represent examples of controllable and uncontrollable fire situations in a moderately heavily built-up central business district (CBD). This appendix describes briefly these studies without going into the details of analysis.

The urban area studied is the CBD of San Jose, California. The two cases represent air bursts of megaton-yield weapons at distances north of the CBD which would result in air-blast peak overpressures of 2 and 5 psi. Primary consideration was given to the initial emergency period. Changes in the target environment at later times were considered, but much more superficially. The current San Jose emergency plans were adopted insofar as they are applicable. A map of the San Jose CBD is included as Fig. A-1. Portions of the area included in the studies are outlined and the locations of shelter structures are indicated.

The study area is quite heterogeneous in make up. It includes a few tall buildings and a large number of 3- and 4-story buildings mixed in with a dominant number of 1- and 2-story buildings. Structural characteristics and occupancy are also quite varied. Wood-frame, masonry, reinforced-concrete, steel-frame, curtain-wall as well as other construction types are represented. Commercial and office-type occupancy prevails, but there is a complete spectrum of occupancy categories, including hotels, theaters, public buildings, churches, warehouses, garages, medical-dental buildings, schools, banks, and stores. Streets are generally broad in comparison to the heights of buildings, and there are several parks and other large open spaces. However, the building density (as indicated in Fig. A-1) for the most part runs well over 20 percent; up to nearly 50 percent in one block. Because of the varied building heights, exposure

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[*]Additional information concerning the case studies is given in Ref. 37.
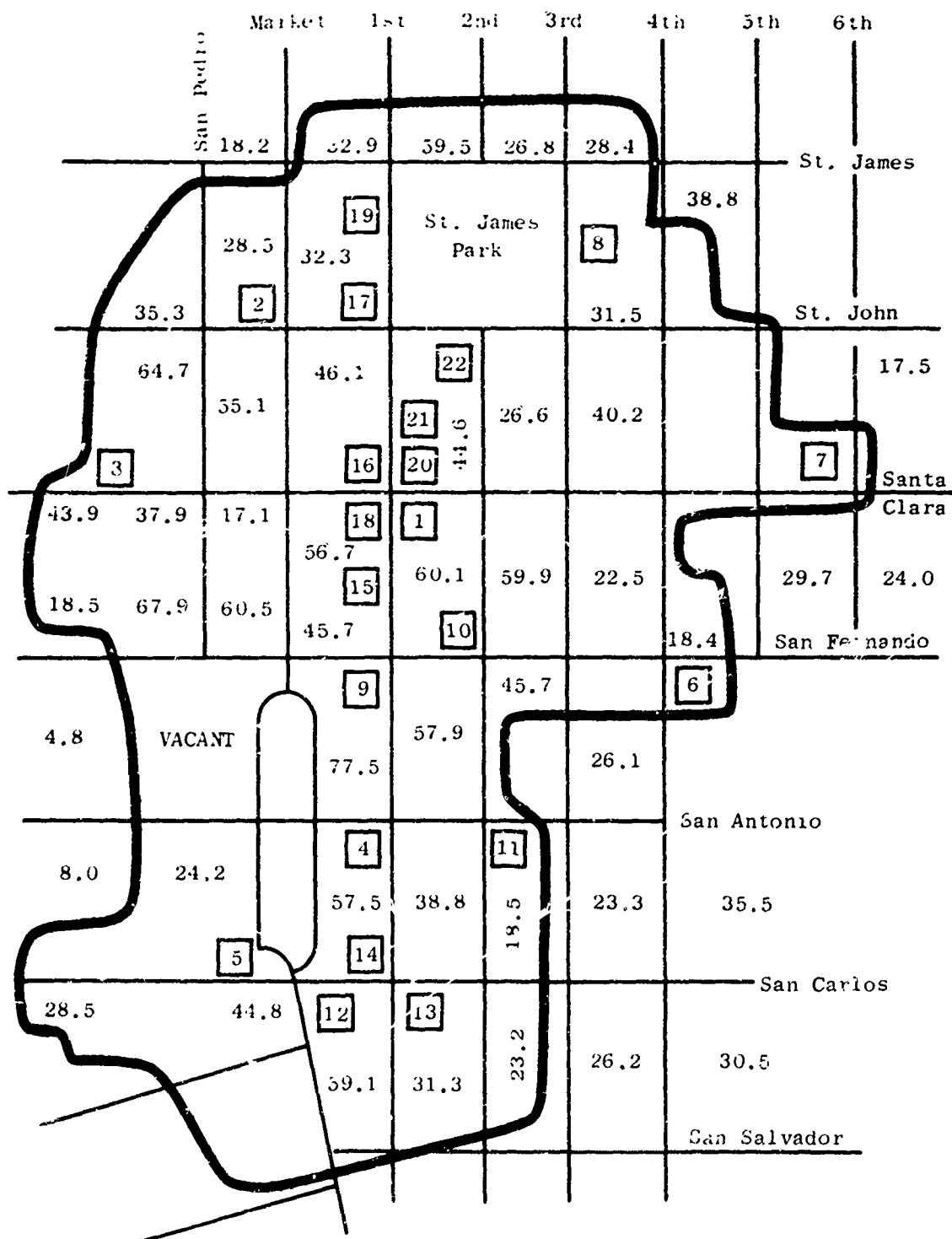
Fig. A-1. Map of the San Jose CBD

of windows by thermal radiation from air bursts such as those postulated for the studies would be high in spite of the building density; and because of the building density, it appears quite probable that a firestorm situation would result if a large fraction of the structures were to burn actively at one time (Refs. 38 and 39). All shelter structures appear to have a high fire risk, either from direct initiation by exposure to thermal radiation from the nuclear fireball or from spread of fire from neighboring structures (both in most cases); and the shelters, most of which are located in basement spaces, provide little or no protection from a fire that might develop in the main structure.

According to current San Jose emergency plans and the assumption that sufficient warning time before the attack was available, the fire services would be totally mobilized and deployed to shelters. The trucks, engines, pumpers and other mobile equipment would be located in the street just outside of the respective shelter buildings. It is to be expected that during the crisis period preceding the attack, particularly during its later stages, the fire service personnel will have busied themselves with implementing thermal-radiation and fire countermeasures, effecting emergency shutdown of hazardous utilities and processes, and recruiting and preparing volunteers for self-help firefighting roles. It is questionable how much of this preattack preparation is accomplished. We have cursorily considered, wherever it seemed appropriate, the probable consequence of implementing a substantial level of self-help preparedness.

The immediate postdetonation response was assumed to be a search for, and extinguishment of, incipient fires in the buildings occupied by the fire services and their auxiliaries which is conducted prior to (but also as a part of) the initial assessment of the controllability of the overall fire threat. No explicit assumption was made of higher echelon guidance or coordination. Subsequent responses were chosen to be consistent with the contingency plans described in Section 4 of the body of this report. The amount and breadth of information needed for making a reliable judgment of fire

controllability may imply, in some circumstances, a dependence on communications with a centralized center of emergency operations having a broader view of the developing fire situation; however, for the cases studied here, we conclude that an adequate judgement can be made by the isolated unit commander on the basis of first-hand observation. The basic decision is whether to stand and fight or to relocate the surviving population while movement remains feasible. A major simplification in these studies derives from the fact that there are no radiological complications imposed by local fallout.

In both of the cases studied, estimates were made of (1) the numbers and kinds of casualties resulting from blast among the general population (assumed to be entirely sheltered), (2) the casualty loss of fire-service personnel from blast (assumed to be in the same proportion as the general population), (3) the damage to fire-service equipment by blast, (4) the damage to water supplies by blast, (5) the overall debris levels in the streets, (6) the number and location of initial fires (both significant and insignificant) in the shelter buildings occupied by fire-service units, (7) the general initial fire density, and (8) the growth and spread of fire in the area (assuming n) control). This provided a measure of the threat, the corresponding demands, and the degradation of fire-service capability to respond to the demands.

CASE 1 (5-Mt-Yield Air Burst, 2 psi Overpressure)

This case was chosen to represent a situation of potentially controllable fires because (1) blast damage to buildings is slight, (2) debris levels in the streets are very light, (3) initial fire incidence is low, (4) damage to firefighting equipment is not significant, and (5) the water supply for firefighting is uninterrupted (although there may be some loss in pressure).

By means of the casualty curves from Section 5 of this report, the survivors and their condition may be estimated. Application of the same casualty rates to fire department personnel yields the number of usable firefighters. The number of initial

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fires[*] in CBD shelter buildings can be estimated. Characteristics of ignitable fuels were assumed to have the "class-average" properties of the survey data taken in Work Unit 2538C (Ref. 12). From the previous graph of vehicle damage, it is seen that at 2 psi, the fire department vehicles will experience light damage at the very most, with broken glass from windshields being the only noteworthy problem. All vehicles should be capable of being driven and operated without delay. Debris levels in the streets are estimated at 1/2 in. or less.

Owing to the small number of initial fires in the shelter buildings, the firemen can quite easily handle all fires in their own shelters prior to 18 min after the attack (the average room flashover time) if action is taken immediately and self-help team tactics are employed. Even if nonprofessional self-help teams were not present in the other CBD shelters, the firemen would be able to travel to these shelters and handle the initial fires either on a self-help or brigade basis with no difficulty.

After initial fires in the shelters have been extinguished, the next consideration is for spread from neighboring buildings and across streets. By employing nonprofessional volunteer self-help teams (assuming no more than 10 percent of the survivors could be used) it appears likely that initial fires could be controlled for all buildings in the block where each of the shelter buildings is located if such action were initiated immediately. Without this, a serious fire threat to the shelter would result.

There are 22 shelter buildings in the CBD study area. Eight of these experience potentially significant fires. Therefore, the fraction of shelter buildings with significant fires is 0.36. On this basis, the fraction of all buildings in the general CBD area with significant fires should be something less than 0.36, since the shelter buildings are generally taller than the average buildings and thereby have more exposed floors and rooms.

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[*]The initial fire estimate includes both significant and insignificant fires, that is, those which are expected to generate a destructive fire and those which will burn themselves out without developing into a destructive fire. The distinction is based on the results of the fire surveys of Ref. 12.

McFarlane (Ref. 40) has reported the percentages of buildings and stories exposed to thermal radiation for various angles of elevation of the fireball and for various building heights. With these data (for the CBD of Toronto, Ontario, which do not appear to be grossly different from San Jose), a fraction can be derived which relates the exposed stories per building for the general San Jose CBD (based on an average building height of about 3 stories) to the exposed stories per building for the shelters only. Application of this fraction enables us to obtain a fraction of 0.13 for the general building population with significant fires in the CBD area.

This result can be extrapolated with distance to provide an initial-fire distribution for CBD-like areas. This is depicted in Fig. A-2. This figure shows both the fraction of buildings on fire and blocks on fire, assuming a random distribution of initial fires. The curve for blocks is derived for blocks containing 15 structures each, which is roughly typical for the CBD study area. The result is not sensitive to the number of buildings in the block as long as the number is large.

For the 2-psi-overpressure case (horizontal range of about 12-1/2 miles) Fig. A-2 indicates that 80 percent of the blocks will experience at least one significant fire. This corresponds to about 30 to 40 percent with one fire, 30 to 40 percent with two, and less than 10 percent with 3 or more.

After extinguishment of all of the initial fires (using self-help tactics) in the blocks containing shelter buildings, the next fire problem originates in the remaining 10 or so blocks of the CBD without shelter buildings. We estimate that these blocks will have a total of roughly 15 initial fires. The fire-service units with self-help aid could handle initial fires in their own blocks in the first 15 min and travel to fires in the other blocks in about 10 min. By this time, most of the fires will have gone beyond room flashover, and professional firefighting activities will be required for extinguishment. The five pumper units in the CBD have, therefore, an average of three fires each to handle.

The worst case is for the unit having the smallest capacity pumper (an output
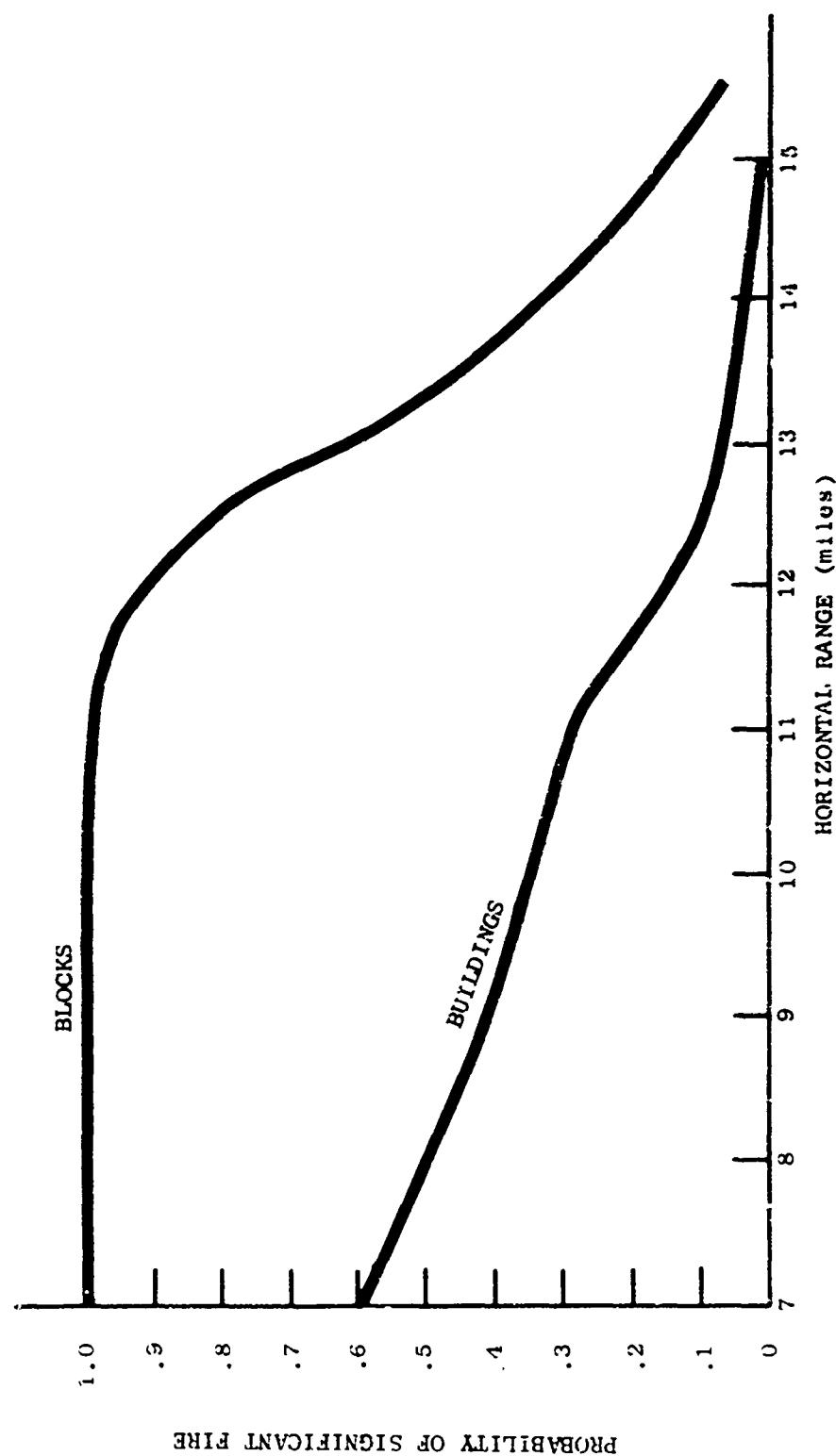
Fig. A-2. Initial Fire Distribution in the San Jose CBD (assuming 15 buildings per block)

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of 750 gpm). Based on the results obtained in Section 5, this represents an extinguishment rate of 750/0.4 or 1875 cu ft/min. Using this extinguishment rate and an initial flashover volume corresponding to the size of one average room in the CBD, an upper-limit estimate for the time required for control of the fires can be calculated. This indicates that the first fire could be controlled in less than 5 min (extinguishment activity starting 25 min after the attack or 7 min after flashover of the initial room). Allowing a full 5 min for control and 10 min for travel to the next fire, the second fire would require about 7 min for control. With another 10 min for travel to the last fire, the control time for it would be about 22 min. All of the fires in the CBD can, thus, be controlled*, even using five pumpers equivalent to the smallest capacity pumper, and the last fire would be under control within about 30 min after the attack.

The only remaining fire problem for the fire services would then be to prevent any fire front which might develop outside the CBD from entering the area. This could best be accomplished at a wide street where the five available pumpers (total capacity of 4750 gpm) could be employed using exposure-control methods, to hold a long defense line. We have not been able to complete an evaluation of the capability to handle this threat within the time available to complete the contract. The practical view of a fire department's capability to hold a fire line of this sort is given in Appendix C.

CASE 2 (5-Mt-Yield Air Burst, 5 psi Overpressure)

This case was chosen to represent a situation of uncontrollable fires because it was anticipated that (1) debris levels in the streets would be quite significant, (2) initial fire incidence would be high, (3) damage to firefighting equipment would be significant, and (4) the water supply for firefighting would be interrupted by a general loss of pressure, certainly in the area considered and probably over the entire city. (See Ref. 41.)

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*All of the pumper-controlled fires are assumed to undergo subsequent final extinguishment and overhaul as a result of self-help firefighting.

Survivors and their condition (for the CBD shelters) can be estimated as in Case 1. The numbers of useful firemen and initial fires may also be estimated for the shelters with assigned firemen. Due to the large number of fires, the activities of the firefighting units were expected to be limited to the shelters they occupy. Accordingly the number of initial fires was not estimated for shelters without firemen. For the 5-psi-overpressure region, all fire vehicles will experience moderate damage. Although some of these vehicles could be repaired to permit operation, it is estimated that from 2 to 4 hours would be required for repairs. Since the water supply is gone and debris levels are fairly high (average of about 6 in.), the pumpers would be nearly useless for firefighting.

With the fire-service personnel acting with no more capability than trained firefighting brigades, they would be able to extinguish all of the initial fires in only one building prior to room flashover. Since water for firefighting is not available, virtually all fires developing beyond flashover are uncontrollable and will spread until the building is consumed. By the use of enough volunteer self-help teams, the initial fires could all be extinguished before room flashover. The number of volunteers required for this effort ran as high as 12 percent of the uninjured survivors for one shelter.

Whereas it appears possible to handle the initial fire situation in the shelter buildings with ample self-help volunteers, subsequent effective fire-control activity will be very limited. Due to the high frequency of occurrence of initial fires, the shelter buildings will no doubt all be threatened by exposure from other burning buildings. Since the water supply is interrupted and the fire department pumpers are not operable, fire-service personnel will be unable to control spread of fire from other buildings. The result will be that most shelter buildings will ultimately be ignited and burned in spite of self-help firefighting actions. The most profitable activity for the fire services appears to be in indicating the need for evacuation to safe refuge from the fires and in aiding the evacuation of personnel.

A-9

Of the shelter buildings in the San Jose CBD, the San Jose Civic Auditorium appears to be the only structure which is potentially an "island of safety" with regard to fire spread from its neighbors. It has one building adjoining it, but no other sizable structures close enough to present a threat. Self-help teams should be able to handle initial fires in the auditorium and adjoining building to provide a structural complex fairly safe from ignition by other buildings. The structures may still be vulnerable to ignition by massive firebrand attack or by a fire-storm environment.

It does appear that a major portion of the CBD may become a mass-fire area. Most of the San Jose CBD has a building density exceeding 20 percent, a fuel density of 8 lb/sq ft of fire area or more, and a total area with this fuel loading exceeding 0.5 sq miles. Certain of the interim criteria (Ref. 38) for predicting firestorms are, therefore, met in this area and a firestorm is potentially possible.

Referring to Fig. A-2, it can be seen that at least half of the buildings suffer a significant initial fire. Our analysis indicates that within an hour nearly every building would be actively burning. Thus all of the interim firestorm conditions of Ref. 38 are met. No realistic amount of fire-service activity (even augmented with the total surviving population) would have the slightest chance of controlling this fire.

Appendix B
URBAN PLANNING AND MUNICIPAL ORGANIZATION FACTORS

A general review of pertinent urban planning and municipal organization factors which appear to have significant effect on fire-service capabilities was performed. In this review each factor was examined to determine the method of implementation, the research required, the peacetime value, and the civil defense value.

The results of this review are presented in Table B-1 and are broken down into the specific areas investigated, such as streets and parks, fire hardening measures, energy and fuel utilities, etc.

Table B-1

URBAN PLANNING AND MUNICIPAL ORGANIZATION FACTORS CONSIDERED
(STREETS AND PARKS)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	PEACETIME VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Wider Streets	Urban renewal. New fire resistant buildings incorporating shelters. Construction slanted to incorporate fire-resistant construction features.	Window protection measure. Fire-resistant landscaping.	Rehabilitate slum areas. Decrease traffic congestion. Decrease fire losses.	Inhibit fire spread due to firebrands and by exposure. Provide better fire survival conditions for people.	Evacuation routes. Rescue routes. Fire-resistant shelter areas.
One-way streets (for emergency)	Traffic planning for peace time and emergency conditions. Effectiveness of fire breaks and streets may be increased by requiring fire hardening of adjacent buildings.	Fire-hardening existing buildings; roofing, windows.	Decrease traffic congestion. Improved fire service.	Inhibit fire spread where buildings adjoining streets are hardened.	Evacuation routes. Rescue routes.
Waterways, rivers, canals.	Usage planning. Landscape banks of waterways and waterfronts for park areas. Provide small craft facilities. Build underground parking facilities which can serve as fallout shelters.	Fire-resistant landscaping	Recreational use. Esthetic value. Reduce water pollution.	Inhibit fire spread. Facilitate the use and movement of fire boats. Provide fire shelter or refuge.	Evacuation routes. Laundone decontamination and rescue.
Park areas and park strips, recreation facilities, institutional grounds.	Planning for use as C.D. fire breaks. Fire-resistant landscaping. Fallout shelter - parking - garages or city facilities.	Same	Recreational use. Municipal beautification.	Inhibit fire spread.	On-foot evacuation routes, fire refuge shelters.
Freeways, and existing wide streets	C.D. route planning. Fire-hardening adjacent buildings. Fire-resistant landscaping. Low-cost shelters incorporated in above-grade embankments.	Fire hardening existing buildings, roofing, windows.	Emergency use.	Inhibit fire spread.	Evacuation and rescue.
Subways and tunnels	Emergency provisions for lighting, ventilation in subways in initial design.	Entryway and exit studies.	Emergency use.	Fire refuge.	Fallout shelter, evacuation and rescue routes.

B-2

Table B-1 (Cont.)

(FIRE HARDENING RESEARCH)

COUNTERMEASURES	IMPLEMENTATION	SPECIAL RESEARCH REQUIRED	PEACETIME VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Fire-hardening of roofs	Require fireproof roofing through building codes and incentives. Should have National Building Code.	Improve overpressure damage resistance of existing fire-resistant roofings. Develop fire-resistant wood shingles. Develop new fire-resistant roofing materials.	Lower fire losses. Lower insurance costs.	Inhibit mass fires and spread due to fire-brand and primary ignitions.	Improve shelter safety, assist evacuation, rescue, conserve lives, and material resources.
Fire-hardening of windows.	Require window protection or fire-resistant contents for primary ignitions. Encourage measures to reduce injuries caused by flying glass.	Fire-resistant window shades. Exterior drop blinds. Automatic venetian blinds. Reverse slanted windows. Special glass. Fire-resistant drapes and curtain. Special screens.	Reduce cooling loads. Reduce fire spread between buildings. Reduce insurance rates.	Inhibit mass fires due to multiple primary interior ignitions.	Same
Fire-hardening interiors	Requirement to supplement window protection. National standards to increase fire resistance of furnishings, walls.	Fire-resistant furniture, floor coverings, interior partitions. Emergency furniture covers.	Reduced fire losses. Reduced insurance.	Same	Same
Fire-hardening of exterior walls	Require masonry or fire-resistant walls, thru building codes and incentives.	Weather-resistant, fire retardant paints. New siding materials.	Reduce fire spread between buildings.	Inhibit mass fires due to exterior ignitions.	Same
Blast-hardening of buildings.	Require building design to maximize inherent strength in materials thru building codes and incentives.	Improve joint strength in frame construction. Improve construction practices to achieve greater strength from materials better shear ties.	Reduce earthquake and wind load damage. Improve fire safety.	Inhibit ignitions due to building damage. Reduce secondary fires.)	Same

B-3

Table B-1 (Cont.)
(ENERGY AND FUEL UTILITIES)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	PEACETIME VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Automatic fuel gas system shutdown.	Require overpressure- or earthquake-triggered valves, pumps, etc. Provide vents to reduce line pressure. Protect shutdown devices and related equipment.	Development of sensing devices and valves where not already developed.	Earthquake fire prevention.	Prevention of secondary fires due to blast damage.	Improve shelter live safety facilitate rescue (conserve resources)
Automatic liquid fuel shutdown, boilers, furnace, refineries, etc., L. P. system.	Require overpressure- or earthquake-triggered switches, valves, shut down, close fuel tanks and drain fuel in system.	None	None	None	None
Automatic chemical plant shutdown	Require overpressure- or earthquake-triggered valves, safety drains.	Development of sensing devices, surplus-loaded valves where not available	None	Prevention of secondary fires, prevent explosions, release of poisonous gases.	Protect population from poisonous, corrosive resources.
Tank farm protection	Upgrade blast-resistance standards, greater separation, more adequate berm protection.	Studies to improve blast resistance.	Decreased insurance rates, increased public safety.	Reduce mass fire threat.	conserve resources
Automatic electric system shutdown.	Require overpressure- or earthquake-triggered electronic system shutdown system. Blast protection for emergency equipment.	Development of sensing devices and system, where not available.	None	None	Improve shelter live safety. Prevent unnecessary damage to electric utility equipment.

B-4

Table B-1 (Cont)
(WATER UTILITY SYSTEMS)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	PEACETIME VALUE	CIVIL DEFENSE VALUE	
				FIRE FIGHTING	OTHER
Fire main emergency provisions	Provide emergency manifolds, interconnections via gas pumps.	Detailed engineering study required for each city. Development of improved repair equipment	Increased reliability of system during peacetime. Increased capability for earthquake fires and peace time disasters	Increased reliability of water supply for fire fighting	Prevent unnecessary loss of water. Light lines to protect steel, etc.
Water system emergency fire provisions	Rerouting plans, special maps, radiation monitoring equipment, personnel shelter. Emergency communication and repair equipment	Detailed survey required similar to fallout shelter location program	Use for peacetime conflagrations, backup for system failures	Increased water supply for mass fire conditions	Increased water supply for shelters
Water storage in buildings	Require water storage in all buildings for extinguishing small fires by occupants. Availability of portable hand pump extinguishers	Development of economical, long-life water storage and access provisions. Development of inexpensive plastic refillable hand pump extinguishers	Earthquake fire prevention. Protection fires, reduced fire service costs	Extinguishment of starting fires in areas served by location and individual buildings	Water available for shelter use and decontamination
Provision for additional water sources	Auxiliary lines and pumps for use of river, lake, ocean as water source.	Detailed survey required similar to fallout shelter location program	Use for peacetime conflagrations, backup for system failures	Increased water supply for mass fire conditions	Increased water supply for shelters
Use of storm sewers and drainage canals for emergency water distribution	Special valves, manifolds and pumps to utilize storm sewer systems for fire-fighting water supply. Special dams, gates, cross ties and pumps to permit use for fire fighting.	Same	Use in peacetime conflagrations. Improve flexibility of system in normal uses	Same	Same

Table B-1 (Cont)

(FALLOUT SHELTERS)

COUNTERMEASURES	IMPLEMENTATION	SPECIAL RESEARCH REQUIRED	PEACETIME VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Fallout shelter fire resistance.	Provide for temporary sealing of shelters during fires. Provide movable insulation supplementary shielding blocks, panels, sand bags, etc. Provide means of testing for O_2, CO, CO_2, etc. Incorporate means for cooling shelter while sealed. Equip with fire extinguishers	Develop permanent and temporary methods of sealing shelter and tent insulation materials. Develop feasible methods of cooling shelter. (Refrig. systems such as external venting of liq. CO_2 thru air cooling heat exchangers.)	Nil.	Permit survival of occupants until fire passes.	Improve shelter conditions for normal use; sealed use
Fallout shelter escape due to fire	Provide hardened escape passages from shelter to adjacent shelter, subway, or external hatch by tunnels, slide chutes.	Develop alternate methods for incorporation in building design at low cost.	Possible use for utility maintenance, etc.	Permit escape if shelter becomes untenable.	Possible use as alternate entrance for shelter use, if required
Backup water supply from building plumbing.	Provide means of draining pipes in building for extra water supply.	Study least expensive methods.	Nil.	Provide additional water for fire fighting.	Provide additional water for shelters
Remote fire surveillance equipment in building.	Installation of smoke detectors, temperature detectors, etc. To minimize fire risk and radiation exposure of fire watch personnel.	Subsidy to develop low cost detection equipment.	Reduced peacetime fire risk and insurance.	Permit detection and extinguishment of small fires.	Permit better decision for evacuation of shelter when necessary

Table B-1 (Cont)

(NEW FIRE CONTROL EQUIPMENT)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	PRACTICAL VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Inert gas or steam release in building	lize system to inject inert gas or steam into certain buildings following warning and evacuation in order to prevent ignitions.	Determine effectiveness of system in reducing primary ignitions and type of buildings where it would be most useful.	Reduce losses in buildings where sprinkler systems cause excessive water damage.	Prevent primary ignitions in buildings where window protection is undesirable. Prevent secondary ignitions in windowless buildings.	Prevent ignitions in buildings adjacent to shelters

B-7

Table B-1 (Cont)

(ELIMINATION OF EXTERIOR KINDLINGS)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	PRACTICAL VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Out-of-doors trash clean up	Revise ordinances to require clean up of fire hazard trash. Utilize fire department and police department for inspection and enforcement. Revise liability laws and ordinances.	Better definition of fire hazard related to trash.	Reduce fire risk and nuisance. Improve appearances. Improve public health.	Reduce mass fire potential due to primary and secondary ignitions of trash.	Improve appearances, public health problems
Indoor trash clean up	Public education program on hazards. Revise liability laws and ordinances.	Same	Same	Same	Same
Safer storage of flammables	Revise ordinances in regard to types, quantities, and method of storage of flammables. i.e., Paint, L. P. Gas, lumber, etc.	Research to determine storage requirements.	Same	Same	Same
Less flammable paper products	Require ignition inhibitors in paper and plastic products likely to result in fire hazards.	Research to determine the economic manufacturing processes or treatments to inhibit ignition of materials which quickly become trash.	Same	Name	Name

Table B-1 (Cont)

(RURAL AREA MEASURES)

COUNTERMEASURES	IMPLEMENTATION	RESEARCH REQUIRED	CASUALTY VALUE	CIVIL DEFENSE VALUE	
				FIRE RELATED	OTHER
Agricultural area fire breaks	Revise fire liability laws for fire damage caused by highly inflammable crops or crop residues or weeds along established fire breaks, roads, streams.	Define vegetation crops and conditions which are hazardous. Find vegetation and crops with low fire spread potential.	Reduction of total fires, and fire costs	Prevent fire spread to inhabited areas and cities. Prevent loss of life and property in rural areas	Conserve resources
Forested area fire breaks	Extend fire break system. Plant vegetation to lower fire spread hazard potential along fire breaks. Improve access roads.	Same	Same	Same	Same
Improved fire detection	Improve methods and efficiency of fire detection systems	Develop advanced detection methods and devices, such as infrared detectors, remote automatic smoke detectors.	Same	Same	Same

Appendix C
A FIRE DEPARTMENT'S VIEW OF ITS OWN CAPABILITY

Early in 1966 the Office of Civil Defense queried the fire department of San Jose concerning its anticipated response and performance following a specified nuclear attack. Chief R. J. LeBeau and his deputies prepared a tactical critique in which they detailed their planning and expectations. Although the fire picture was not so well-established then as it now is, we feel that Chief LeBeau's critique is still of considerable interest to those concerned with the planning and conduct of fire department operations in nuclear emergencies. The statement of the problem, as presented to Chief LeBeau by OCD research, is not reproduced here. Certain of the assumptions contained in the problem statement serve to clarify the response and are given below. It was assumed that:

1.   There is no radioactive fallout in the area.

2.   Only the single detonation affects firefighting operations in San Jose.

3.   The water pumping and electrical power stations remain operative.

Portions of Chief LeBeau's response are reproduced below with his consent, [*]

> The maximum wind listed on the days designated are for short periods. The average wind for each 24 hour period or for each six hour period in each 24 hour period would make it easier for us to project the speed of the fire and the placing of our fire equipment. The average wind velocity for August 1963 was 5 MPH from the west which we have used for the problem.

> The attack on the date and time (Thursday 24, August 1965, 8:52 PM) specified would find the San Jose Fire Department pretty well organized. San Jose had been in Redcon One (1) for two days. All

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[*] Letter of consent; Chief R. LeBeau, San Jose Fire Department, to D. B. Wallace, dated Dec. 6, 1967.

Firefighters would be available for duty and we would be at 100%
of our effectiveness. We would also need to know how much out-
side firefighting aid we could expect and how soon we could expect
any aid before we could effectively set up our fire defensive lines.
Without additional aid, with the fire conditions you describe, we
would be hard pressed to save 1/2 of the city. We have not figured
on any outside aid except for the City of Santa Clara which could not
defend itself but would have most of its fire equipment undamaged.

The firefighting force of San Jose is 369 men. There are nine
District Chiefs, 83 Captains, and 250 firefighters on the line. The
rest are overhead personnel. We have seven ladder companies and
twenty-two engine companies in service at all times. On Redcon #1
we would also put the seven reserve engine companies in service
which we call "Reserve #1 through Reserve #7". This would give
us a total of 29 engine companies and seven ladder companies. In
addition we would load available pickups, flat beds, trucks, trailers,
etc. with the spare hose and run one "hose wagon" with each engine
company giving the engine companies more than 100% more fire-
fighting ability when necessary manpower is added. Any physically
fit man can fight fire so that two "laborers" will be assigned to each
firefighter, for direction, which will basically give us 750 pro-
fessionally directed firefighting personnel who can effectively be
commanded by the 83 Captains and 9 District Chiefs of the depart-
ment. The city would be cut into districts with a District Chief in
charge. He would be assigned men and companies under his immediate
direction subject to the overall direction of the Chief of the Depart-
ment who would have the "whole picture."

As soon as the blast, fallout, and fire effects were known the
Fire Service would advise the Emergency Operating Center to
evacuate and move to the south and west all the people in the 18
shelter complexes located in the 8 to 12 mile radius from the bomb
burst. This would allow the Fire Department to concentrate on the
fires without the additional responsibility of protection of the large
numbers of people who would be concentrated in the shelter areas.
This is one of those problems in which not only the fire service, but
all agencies in the Emergency Operating Center would have to coordi-
nate. If there was fallout from other blasts in the Bay Area, the
possibility of more weapons in the San Jose area and the general war
situation would have to be evaluated in a real situation, but for this
problem, with the single 5 MT weapon and no fallout, we would move
the bulk of these people in the shelters to the south and southwest of
the city or send them to their homes to help fight and prevent fires.

C-2

You did not give the extent of blast damage but we feel that the
zone out from the blast for seven miles out would have all buildings
destroyed, highways and streets impassable, vehicles unusable,
overhead electrical power destroyed, and at least 30% of the people
killed. Very little of this area is in the city limits of San Jose. The
first consideration is keeping the remaining people alive and safe
from the fire effects. There would be some buildings destroyed
within San Jose with people trapped. Rescue of these trapped people
would be given a high priority but would have to be weighed against
the fire protection of hospitals, shelter complexes, routes of escape,
and the general firefighting. The seven ladder trucks, each with
twenty men, would be committed to light rescue work which should be
completed within a few hours.

The average householder would be able to put out fire in his home
with the help of his neighbors whose homes are not involved. In the
8 to 12 mile range one out of five homes has a fire started in a room
or two or on the roof. As there are about 30 homes in the average
300 foot by 600 foot block, this would give us 6 fires in each block
of this area. We feel that 5 of the 6 fires started would be put out,
while small, by the tenants. This would leave one fire in each
square block that would do one of two things if left without any pro-
fessional firefighting. It would burn itself out or extend to other
structures. One out of every two of these fires would burn itself
out with the help of neighbors protecting the buildings on each side
of the burning house. This would leave one fire in every two square
blocks that would need heavy firefighting help from fire trucks and
professional firefighters. We have tried to be conservative in this
estimate. The average person, in time of emergency, does more for
the protection of his own property than we are inclined to give him
credit for. The continued water pressure in the mains is the key to
this firefighting ability.

One tenth of the fire hydrants in San Jose are of the "wet barrel"
type which would flow if knocked over and damaged. There would be
several crews (of two men) in pickup trucks assigned to the detail
of finding any fire hydrants which were knocked over and shutting them
off at the valve from the main. With this operation we feel we could
maintain at least 30 pounds pressure in the water mains. The City
of Santa Clara has its own water system so the damage to its water
system would not lower the pressure in our mains. In addition the
San Jose Water Works has gravity flow from the reservoirs in both

the east and west hills so that San Jose is not 100% dependent on
electrical power for water pressure in the mains. Without this
constant water supply the fire service could not set up a defensive
line and hold it for any length of time.

The Water Conservation District maintains water dams on the
Los Gatos, Guadalupe and Coyote Rivers which are not normally dry
at this time of the year. We would ask them to release water in
these rivers and have these rivers as an auxiliary source of water in
about 6 hours after they release water from the dams.

Overall fire service command would have to be established. By
this we mean coordination and cooperation with the cities other than
San Jose that are affected. Campbell, Santa Clara, Los Gatos,
Milpitas, and the Santa Clara County Central Fire District would have
to be coordinated to do the most effective job of fire protection of the
community as a whole. In the problem we have used only the men and
equipment of San Jose and Santa Clara Fire Departments as the other
departments would be busy with the fires within their own city limits.

We would ask the State Civil Defense Office for fire equipment
and firefighters from all other available jurisdictions as well as fire
retardant "bombers" from the California State Forestry Division.
This fire retardant, if available, would be used to coat the roofs of
structures on our fire defense line or to cut off the extension of any
fire front that was out of control of the firefighting forces.

If fire equipment of the City of Santa Clara was forced to drop
back behind our fire defense line their equipment and manpower could
be put to good use in the overall protection of the metropolitan area.

With about 500 square blocks in the 8 mile to 12 mile zone San
Jose would have 250 fires beyond the capacity of the householders and
need of fire equipment and professional firefighters. This, of course,
is in addition to a fire front that would burn out from the 7 mile "initial
fire area" and would have to be stopped at our fire defense line. There
would be less than the 250 fires behind our fire line of defense as the
defensive line is roughly 10 miles from the weapon drop zone. However,
there would be 100 or more fires that would have to be considered and
coped with before we could consider our position on the fire defense
line secure.

In the 12 mile to 15 mile area we have one fire in each ten homes
or structures. These fires would tend to be less severe and the house-

holders could put out 14 out of 15 of these fires while small. Using
the same ratio as above we would have one fire beyond the capability
of the householders in every nine blocks. As there are 700 square
blocks in this area we would have about 100 fires in this area that
would need professional firefighting and the use of fire equipment.

As an initial line of fire defense we have chosen the Nimitz
Freeway, (Interstate 680 and Interstate 280) running from Oakland
to Santa Cruz and Junipero Serra Freeway (recently completed).
This is shown on the map* by a heavy black line. We feel that the
fire service could not cope with the severe multiple fires on the
"bomb side" of this line. We would fight the fires that householders
are unable to cope with in the 12 to 15 mile area and behind the line
established in the 8 to 12 mile area. This broad freeway could be
held from the fire burning out from the initial fire area.

A survey of the fire situation from a helicopter would be absolutely
essential to establish and maintain our line of defense. We would not
only have to make this initial survey by air but would have to continue
to survey the situation to prevent fire companies from being trapped
or otherwise to be waging a hopeless fire battle.

The main concentration of firefighting equipment and firefighters
would be on the fire line from Stevens Creek Blvd. to The Alameda.
This two mile area would be the hardest to defend due to the build
up on both sides of the freeway and to the west wind. We would be
forced to sacrifice every structure to fire and blast north and west
of the fire defense line. Attempting to move the fire defense line
toward the blast would place more severe fires behind our line.

We would commit at least 15 engines on the fire line in this two
mile defense line. The rest of the engine companies and firefighters
would be assigned to rear areas under a District Chief. With constant
surveillance from the air this fire force would be kept flexible and
able to concentrate on fire fronts jeopardizing our fire line, knock
them down and move to another place of danger on the fire line.

The foregoing has been background material for your specific
questions. In answer to your questions of "Initial Fire Area" after
the first half hour or one hour, all the built up area in the drop zone
to a seven mile boundary would be the initial fire area. No school,
major building or open area within this fire area, that is built up,

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*The map mentioned here is not available for reproduction.

would provide a safe refuge for people. The large open areas around the bay and away from built up areas could be used as a "refuge". However, these people would be suffering from the blast effect and would need immediate help for their many problems. They would be safe from fire but have some difficulty with smoke in these areas. The initial fire area is marked: the end of a 12 hour, 24 and 36 hours are also marked on the map. The first 12 hour (blast time to 8AM) period would find the fires behind the fire defense line small and with temperature down during this night period, humidity up, wind down, and the fire fighting forces fresh with effective equipment. The next 12 hours (8AM to 8PM) would find the temperature up, wind stronger. humidity down, remaining fires larger, and the efficiency and effectiveness of the fire forces starting down. There would be some break down of equipment on an ever increasing degree during this period. The initial firefighting effort would be made during the first 12 hours after the burst with an all out effort of men and equipment to put out the scattered fires behind the fire defense line. The daytime period of August 25th would see the fire front extend more rapidly from the 7 mile initial fire area toward our lines at which time fresh crews would have to be available to meet the fire at the fire defense line. The "spot fires" behind our fire defense lines would be taken care of on a "knock down and move on basis". We would use large streams and when the fire was down to the place where the householder could take care of the fire with garden hose we would move on to another fire needing large streams of water.

The initial fire areas in the 8 to 12 mile area would be one (1) fire beyond first-aid firefighting in every two square blocks. As San Jose city limits and the fire defense line is, on the average, over 10 miles from the drop zone the incident rate of fires would be one-half of that or one (1) fire every four square blocks. On a "knock down move on" basis these fires, on the average, would require 30 minutes of firefighting by one engine and 15 firefighters. The longer these fires would be let go the larger they would become and the longer it would take to stop them. This 30 minute estimate for each fire is based on the first 12 hour period.

There would also be some initial fire areas in the 12 to 15 mile area and as in the 8 to 12 zone would require the "knock down and move on" firefighting method. These would tend to be less severe than the fires in the 8 to 12 mile area and we would have to say that 20 minutes, on the average during the first 12 hours, would be

required to stop them. These fires would also tend to spread so
that the sooner we got at them the quicker the fires would be put
out.

The "fire defense line" drawn on the map would be flexible.
We could move up equipment and men in several areas past this line
but when we move up past the fire line it must be remembered that
it will leave more fires behind our fire line. The fire defense line
was chosen because we feel that we can stop the fire front at that
line plus coping with the fire at the rear of that line. We feel that
this line can be held. However, we cannot be positive that we can
prevent the numerous fires that are behind our lines from extending
and forcing us to move our lines back to a secondary defense line.

Water to fight the fire is a prime consideration. As the freeways
described as our fire defense line do not have water mains on them
it is necessary to move hose up from the streets behind this line
to provide protection. It is possible that in an area that is clearly
going to burn to our defense line that we would "back fire" the
structures toward the fire front. Bulldozers would be used in the
same way to remove structures that may add to our fire problem on
or near our fire defense line. This defense line would be strengthened
during the period from when this line was first chosen as our fire
defense line and the time the fire burned from the general initial fire
area to this line. Back fires, bulldozers and ship loaders could be
used to widen this line to prevent the general fire area from crossing
to the west and southwest.

The initial fire area inside the 7 mile zone would be burned out
in a 12 hour period but would smoke for several days. The fires
started in the City of Santa Clara would merge in the twenty-four to
thirty-six hours. The areas of fire would approach our fire defense
line, not all at once, but in first one area and then another and not
all in one mass of fire. By remaining flexible we would be able to
concentrate at the fire points that reach our lines, knock them down
or back fire to them and then move equipment to another area of
danger. The areas that were burnt to our line either through back
fire or burn out from the fire front would provide no further fire
problem and release the men and equipment which were needed in
that area to other line areas or to fire areas behind our lines. The
"fire front" from inside the 7 mile area would approach our desig-
nated fire line of defense within 24 to 36 hours after the initial weapon

burst. All of the firefighting forces would be used on the "spot"
fires behind this defense line up until the time they were needed on
the fire front or defense line. This period would be used to evaluate
the situation and establish where we could establish our fire defense
line and still hold the fires in check in our rear areas.

The number of people leaving their homes in the 8 to 12 mile
area to the south and southwest would be considerable. Roadways
would become quickly congested and the bulk of people would be
forced to walk to safety. The fire department would keep the main
"escape routes" free from mass fires within our fire defense line.
The San Jose Airport would provide a safe, temporary refuge for
the people from the City of Santa Clara.

The people who are able to walk in the Sunnyvale area should
walk west. The Mountain View and Los Altos area should walk
south staying in the open areas. The weather in August would not
cause a great deal of discomfort due to cold or exposure.

Assignment of firefighting personnel would be a major considera-
tion in a long firefight of this type. The initial fight would be "all
out" with all firefighters and equipment committed for the first 12
hours. After that two Captains and 24 firefighters would be assigned
each engine and truck company to be rotated on a 4 hour on -
4 hour off schedule. This would give us one Captain and twelve
firefighters on each piece of equipment at all times with an effective
crew. Within forty-eight to sixty hours from the weapon blast the
fire service should have all major fires under control and be able
to allow some firefighters more rest and the hose, tools, engines,
ladders and trucks could be serviced, fixed when necessary, and
we would be in the recovery phase. However, many fire areas would
have to be patrolled to prevent rekindle. Smoke would be a down
wind problem up to 72 hours after the initial blast.

The heavy equipment (fire engines, trucks, etc.) must be kept
in gas and oil and serviced at regular intervals - otherwise it will
break down and be of no value to us. The gasoline tankers and the
lube trucks would go to each engine and truck to provide lubrication,
oil, replace lights and plugs as necessary. The shop mechanics
would be on an on-call basis to all equipment to render automotive
first aid and keep the equipment running. All men with a mechanical
background would be used to keep equipment in operation.

DOCUMENT CONTROL DATA - R&D

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1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
URS Corporation 1811 Trousdale Drive Burlingame, California	UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

Fire-Service Capabilities for Damage Control and Rescue

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report

5. AUTHOR(S) *(Last name, first name, initial)*

Martin, S. B. Ramstad, R. W.
Staackmann, M.

6. REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO OF REFS
March 1968	154	41

8a. CONTRACT OR GRANT NO	9a. ORIGINATOR'S REPORT NUMBER(S)
N00228-67-C-0694	URS 673-3
b. PROJECT NO	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. OCD Work Unit 2512A	NRDL-TRC-68-8

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	Office of Civil Defense Office of the Secretary of the Army Washington, D. C. 20310

13. ABSTRACT

This study examines the capabilities for fire-control and rescue activities by the fire services following nuclear attack on urban areas. The subjects treated include: (1) feasibility of various strategies and tactics; (2) guidelines for tactical decisions for limited-information cases; (3) resource and manpower requirements for typical operations; (4) rationale for allocation of services to demands; and (5) basic concepts of a method for evaluating performance. The research reported accomplished the following: (1) development of analytical methods and preliminary performance models; and (2) studies of specific cases to test the analytical methods and to provide a preliminary evaluation of some operational concepts. A follow-on study is recommended to bring the research to a conclusive stage.

DD FORM 1473 (1 JAN 64)

14		LINK A		LINK B		LINK C	
	KEY WORDS	ROLE	WT	ROLE	WT	ROLE	WT
Fire Services Damage Control							
Capabilities Rescue							
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Strategies							
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